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"A. S. 'Double' E."*

A. S. "Double" E. has taken an important step in joining with our other national engineering societies in carrying forward scientific engineering progress and achievement in this post-war era.

The interests of the Society have long been devoted to the problems of "what to teach" and "how to teach." It has, however, given increasing attention to the development among engineering students of that fundamental background of common understanding and objectives, the encouragement of a proper perspective with regard to their place in society, and the attainment of those high qualities of character and professional ethics which are such essential factors to successful engineering service.

The Society, in taking this new step, assumes added responsibilities. Our power for peace in this troubled world and our faith in democracy as a means of providing higher standards of life, as well as living for all our people, rest upon our continued leadership in science and engineering. We must play our part not only in research and in the continued development of improved methods, processes, and products, but also in guiding the evolution of our economic, social, and political life so that it may be integrated with such developments. We must seek those optimum conditions under American Democracy which will stimulate continued scientific and engineering progress and make it certain that we shall lead the world in the never-ending search for a good life for man.

It is our hope that A. S. "Double" E. will fully recognize its new opportunities and accept this challenge to wider service, and will take its place as a leader in solving these basic problems of an adaptive society.

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UNESCO, A Program for Peace through Understanding

By HUBER O. CROFT

President of the Society and Representative on UNESCO

In November 1945, something new under the sun was conceived at the United Nations meeting in London. It was called the United Nations Educational, Scientific and Cultural Organization (UNESCO). Briefly, the aims and objectives were to be the unrestricted pursuit of objective truth, the free exchange of knowledge, the development and expansion of means of intercommunication between peoples, and the fostering of mutual understanding of each other's lives. In other words, UNESCO ultimately dreams of reaching a Peaceful world through fostering the sympathetic understanding of the peoples of the world. *"Since wars begin in the minds of men, it is in the minds of men that the defenses of Peace must be constructed"* is a portion of the preamble of the constitution of UNESCO. This brief statement epitomizes the whole of UNESCO.

To implement UNESCO, each member nation was invited to select a representative delegation to an international General Conference and to form an Advisory National Commission. In July 1946, the Congress of the United States officially recognized and financially supported UNESCO by providing that the President with the consent of the Senate should appoint five delegates to attend the international General Conference, and that the Secretary of State should appoint a National Commission from the "principal national, voluntary organizations interested in educational, scientific and cultural matters" and from outstanding citizens.

This action by Congress was unique in that a group representing some sixty voluntary educational organizations was asked for advice as to how a yearning for Peace could be matured and brought to fruitful ends by fostering international understanding between peoples.

The American Society for Engineering Education was one of the organizations invited to become a member of the National Commission. The first meeting of the National Commission was held in Washington from September 23rd to September 26th. During this meeting under the leadership of Mr. William H. Benton, Assistant Secretary of State, The National Commission was subdivided into the following working committees: Education, Mass Communication, Cultural Institutions, Natural Sciences, Social Sciences, Humanities and Creative Arts. Each committee brought back recommendations for adoption by the whole commission. In view of the historical importance of the final recommendations of the National Commission, the document is given here in toto:

"The United States National Commission for the United Nations Educational, Scientific and Cultural Organization, organized in accordance with Section 3 of House Joint Resolution 305 of the 79th Congress (Public Law 565, 79th Congress, Chapter 700, 2d Session), met in Washington from September 23 to September 26, 1946, to advise the Government of the United States and the United States Delegation to the first General Conference of the United Nations Educational, Scientific and Cultural Organization on matters relating to the Organization, and specifically on the position to be taken in the Organization by the United States Delegation.

"The purpose of the Organization, as stated in its Constitution, is to contribute to peace and security by promoting collaboration among the nations through education, science and culture. The Organization is not conceived of, in other words, as an international undertaking to promote education and science and culture as ends in themselves, but rather, through education and science and culture, to advance the peace of the world.

"In the opinion of the National Commission, the position to be taken by the American Delegation in the General Conference of the Organization should be determined by this purpose. The American Delegation should support those proposals for action by the Organization which give promise of advancing directly and significantly the cause of peace through understanding. The necessity of this labor grows clearer from day to day as the effects of misunderstanding and distrust and fear upon the the conduct of international relations become increasingly evident. The recognition of the fundamental community of human interests which made possible the great collaborative effort of the war has diminished with time and change, and the possibility of common effort for peace and for security has diminished with it. To restore and make increasingly articulate the intellectual and moral solidarity of mankind—to identify and analyze existing obstacles to that solidarity and to develop action which will strengthen or create forces to overcome them—is the most immediate and the most urgent need of our time.

"In the opinion of the National Commission, the responsibility of the United Nations Educational, Scientific and Cultural Organization in the present crisis is so great and so pressing that the Organization should not hesitate to employ any proper means, however novel or however costly, which give promise of success. The Organization is itself a new agency, daring in purpose and novel in structure. The means it employs should be appropriate to its nature. It must serve as the cutting edge for international action. If annual military expenditures of thirteen billion dollars for the defense of the people of the United States against attack are justified, ten per cent of that amount, and far more than ten per cent, might well and wisely be expended to remove or greatly reduce the danger of attack. It would be cheap insurance. In the first place, it is the consensus of military opinion that no adequate military defense against the weapons of modern warfare exists. In the second place, even if such measures were available, their cost in terms of life and suffering are so inestimably great that any action which would diminish the necessity for their use would be economical.

"The budget of UNESCO cannot now be estimated. The National Commission believes, however, that a budget in the amount of a billion or a billion and a half dollars or even more might well be justified, if practicable and useful projects requiring such expenditures presented themselves. The National Commission pledges itself to support the Organization to the limits of its power so far as the contribution of the United States to the budget of UNESCO is concerned.

"But though the American Delegation should be prepared to think and to act boldly and imaginatively in the General Conference of UNESCO, it should never forget, in the opinion of this Commission,

that it represents a people deeply and firmly committed to certain fundamental propositions bearing upon the nature and destiny of man. It should hold unwaveringly to the absolute requirement of freedom of thought and freedom of expression as the basic means of arriving at the world understanding which is the immediate as well as the ultimate objective of the Organization's labors.

"The Commission has considered a large number of proposals for action by the new Organization as developed by a Preparatory Commission established in London by the Conference of the United Nations which drafted the Constitution of the new Organization in November, 1945. These proposals will be reviewed at the meeting of the General Conference of UNESCO. Accordingly, the National Commission has considered the report of the Preparatory Commission as a point of departure and has not hesitated to develop and to advance additional or different ideas of its own. The present report of the Commission does not undertake to list in full the recommendations adopted by the National Commission in the various fields of UNESCO's activity. Many of these, specific and detailed in character, are submitted to you in a document supplemental to this report for such use as you may think wise to make of them. The Commission believes that these recommendations should be supported by the American Delegation in so far as they are not inconsistent with the general principles laid down in this report. The recommendations here listed are the recommendations to which the Commission attaches greatest over-all and present importance. They are, moreover, recommendations which, in the opinion of the Commission, best illustrate the character of the work UNESCO should undertake.

"We have arranged our proposals in terms of the functions of the Organization as defined in the first Article of its Constitution. Fundamentally, the concern of the Organization is with the relations of men to each other. It approaches these relations in terms of three kinds of international collaboration. First, international collaboration for the *preservation* of men's knowledge of themselves, their world and each other; second, international collaboration for the *increase* of that knowledge through learning, science and the arts; third, international collaboration for the *dissemination* of that knowledge through education and through all the instruments of communication between the peoples of the earth in order that understanding may replace mistrust and suspicion and the fear which leads to war.

"In the opinion of the Commission, the order of present urgency puts the third of these functions first. The Commission, therefore, recommends at this time only a limited number of projects in connection with the first and second activities of the Organization.

"(1) *International Collaboration for the Preservation of Men's Knowledge of Themselves, Their World, and Each Other.*

"Here the Commission recommends that the American Delegation advance and support proposals for action looking toward the rehabilitation of libraries, museums, scientific laboratories and educational institutions and other depositories of the materials and tools of art and learning. The Commission does not feel that it is appropriate for the Organization under its Constitution to attempt the work of reconstruction and rehabilitation itself. The Organization is, however, the only body which can properly direct a general study of needs and draft a plan of action.

"(2) *International Collaboration for the Increase of Men's Knowledge of Themselves, Their World and Each Other through Learning, Science and the Arts.*

"Here the Commission feels that the American Delegation should advance and support proposals looking toward the development of conditions more favorable to the creative and investigative work of artists, scientists and scholars. Where agencies capable of improving these con-

ditions in whole or in part already exist, the Organization should give its active support and encouragement to their undertakings and should attempt to facilitate their cooperation with each other. Furthermore, the Organization should encourage the establishment of new agencies of this character where they are needed but do not already exist.

"The American Delegation should advance and support proposals for studies by the Organization of social and international tensions which create obstacles to international understanding and therefore to peace, and for action by the Organization to encourage the development of appropriate means for their elimination.

"The American Delegation should advance and support proposals for the establishment of new scientific and scholarly projects for research in fields in which work can most effectively be undertaken on an international basis, as, for instance, research in meteorology, oceanography, international health, and the study of epidemic diseases.

"(3) *International Collaboration for the Dissemination of Men's Knowledge of Themselves, Their World and Each Other through Education and through all the Instruments of Communication.*

"The American Delegation should advance and support proposals for the establishment of the reestablishment of the means of international communication through education and through all other media where they are needed and where they are at present lacking.

"The American Delegation should advance and support proposals for the establishment by the Organization, alone or in connection with the United Nations, of a world-wide radio network capable of laying down a strong and consistent signal in all major areas of the world.

"The American Delegation should advance and support proposals for the removal of obstacles to the free flow of information in accordance with the report of the Committee of Consultants to the Department of State on Mass Media and UNESCO. The Commission differs, however, with the Committee of Consultants in believing that the Organization should concern itself with the quality of international communication through the mass media and should give serious study to the means by which the mass media may be of more positive and creative service to the cause of international understanding and therefore of peace. The Organization should, of course, avoid at all times any act or suggestion of censorship.

"The American Delegation should advance and support proposals for action to free the channels of international communcation of obstacles created by discriminatory or unduly restrictive copyright legislation, discriminatory or unfair rates, or other similar practices or laws.

"The American Delegation should advance and support proposals that the Organization concern itself with the press, radio and motion pictures, and all other means of publication, reproduction and dissemination of materials, as instruments at the service of art, education, culture and scientific advancement in the labor of international understanding, and with the protection of the peoples of the world against any misuse of these media such as might result in their degradation and perversions to the point of fostering international ill-will and misunderstanding.

"The American Delegation should advance and support proposals for the investigation by the Organization of methods of education for international understanding and for the development of attitudes conducive to peace. Such investigations should direct themselves to the processes by which nations organize and give practice, within their own boundaries, to their people in the arts of peaceful cooperation. They should be more than mere fact-finding investigations. They should be sociological studies of great scope and depth.

"The American Delegation should advance and support proposals that the Organization call a conference in the

year 1947 on the principles, policies and procedures to be followed in the preparation of textbooks and other teaching materials. This conference should include in its membership classroom teachers from all educational levels, school administrators, writers, publishers, and other experts in the production and use of instructional materials.

"The American Delegation should advance and support proposals for the exchange of students, teachers, scholars, artists, artisans, scientists, government officials, and others, active in the various fields of the Organization's work.

"The American Delegation should advance and support proposals looking to the increase and improvement of the access of the masses of the people throughout the world to printed and other materials of intellectual informational and cultural significance. The Commission believes that the American Delegation should advance and support proposals for the development by the Organization of an effective system of international inter-library loan, in original or copy, together with the development of necessary international finding lists, and arrangements to avoid duplication in abstracting and bibliographical services.

"The American Delegation should advance and support proposals for the encouragement of the establishment of popular library and museum systems in those areas of the world where such systems do not now exist."

The National Commission elected the following officers: Chairman—Milton Eisenhower, President, Kansas State College; Vice Chairmen—Edward W. Barrett, *Newsweek;* Arthur Compton, Chancellor, Washington University; and Waldo G. Leland, American Council of Learned Societies.

The delegates selected by President Truman to attend the Paris conference were: Mrs. Anne O'Hare McCormick of the *New York Times;* Mr. Arthur Compton, Mr. William H. Benton; Mr. George Stoddard, President, University of Illinois; and Mr. Archibald MacLeish, Assistant Secretary of State. The Paris conference has now closed but unfortunately its final actions have not been received as this is written.

There was some criticism evident in the National Commission because of some fifty national organizations which were invited to join in the work of the commission only five of the National bodies represented Scientists and Engineers. However, it became apparent as the meeting progressed that the most difficult problems which must be solved were those in Human Relations. In this very baffling field scientists, who deal primarily with recognized facts, like other specialists, are at a loss to agree on the very basic facts themselves in the field of Human Relations.

It was a great honor for the Society to have been selected for the National Commission and a privilege for the writer to have contributed even just a bit to this priceless work for Peace. In the immediate future, another article will be submitted to suggest concrete proposals as to how we as engineering educators can do our share in promoting the aims of UNESCO.

The Senior Thesis in the Undergraduate Curriculum *

By M. A. HUNTER

Dean, Rensselaer Polytechnic Institute

The writing of a thesis has been an integral part of the undergraduate curriculum at Rensselaer for many years. The earliest record places the first recorded thesis in 1835. Since that time, all candidates for degrees in engineering and science have presented a thesis as the final act in their academic career before graduation.

This procedure was interrupted on two occasions only: the first in the year 1918, the final year of World War I when the student war training program (S.A.T.C.) made it impossible to continue thesis preparation, and again in 1943–1945 in World War II when the exigencies of N.R.O.T.C. brought about a similar situation. On both occasions, however, when the pressure of war training was relieved, the thesis was reinstated in the regular curriculum.

Time Assignment in the Curriculum

For the large majority of the student body, Rensselaer has set aside six credit hours for the preparation of a thesis during the last term of the senior year. In special cases, some of the more brilliant students have elected to take six credit hours in each of the two terms of the senior year.

In the normal course of operation at the Institute, the academic term of 18 weeks is divided up into fourteen weeks of advance studies followed by three weeks of review and concluding with one week of examination. In the second term of the senior year, the advance and review terminate at the end of fourteen weeks and the four-week period intervening before commencement is devoted entirely to the final preparation and reading of theses.

The author of the thesis can, under these conditions, find at least 200 hours of time regularly assigned for thesis preparation. In many cases, however, students have devoted considerably more time than this to the thesis. Some of the more forward-looking individuals have chosen their subjects for thesis at the end of the Junior year and have begun operations in the summer preceding the Senior year. Others who are sufficiently interested find time at odd hours and after hours to pursue their thesis studies. This can be called an extra-curricular or co-curricular activity, if by this term we mean those things we do with pleasure after our assigned chores are completed.

The last week of the final term is devoted to thesis reading. The stu-

* Presented at 54th Annual Meeting, S.P.E.E. (Graduate Study), St. Louis, June 20, 1946.

dent is called upon at a time assigned to read his thesis before an audience of any faculty and student members who may wish to attend. He has usually fifteen minutes in which to summarize the results of his work, using slides or drawings or other aids at his discretion. The criticism which follows is mostly from faculty members, and the student steps down from the platform to make way for another, after less than thirty minutes of operation, with the feeling that he has completed the most trying ordeal in his academic curriculum.

Choice of Subjects

In so far as it is possible, the student is allowed a free choice in the subject matter of the thesis which he elects. It is here that the faculty have the best opportunity for finding out where research and engineering talents really lie.

There are a few who present subjects which are entirely original in character—in fields in which no member of the department is actively engaged. These men refute the argument that the student has too little knowledge to develop originality. Some pessimists have said that we are more original at six than at sixteen because in the interim we have been subjected to ten years of regimentation.

A second group of students will elect their thesis studies in the fields of operation in which some professor in the department is actively engaged. Fired by the enthusiasm of a leader, aware of the satisfaction which he derives from his work, and the incident prestige which comes from association with him, the undergraduate finds in this the full flowering of professor-student relationship.

There still remains a third group of students with less imaginative minds for whom the writing of a thesis is a chore which has to be done to meet the demands of the curriculum. These men are assigned topics by the staff in some field of their previous academic experience.

The writing of the thesis is to many of the students the last act in their formal education. They proceed from this to a job in industry. To others, it is an introduction to graduate study and graduate research. To each of them it is the first time at which he has been called upon to undertake an extended project of his own, to concentrate on it over a reasonably long period of time and to produce results which will withstand the criticism of his peers. His previous experiences have been of short duration. But the outstanding feature in the writing and presentation of a thesis at this stage of his career is that he stands for the first time alone.

Advantages Derived from Thesis Presentation

Every student before casting his thesis in final form must consult with a member of the English department and secure final approval for text and arrangement.

One of the professors of that department, as an unbiased observer over many year, rates some of the advantages of thesis preparation in the following summary:

1. It serves to bring together and synthesize material studied in a number of courses, thus obviating comprehensive examinations but forcing the student to make a careful and complete review.

2. It offers a bridge between college and actual practice, since the thesis parallels actual problems met in industry.

3. It provides the stimulus for some average students to do excellent work, since the problem presented by the thesis often seems more realistic and challenging than any other college work.

4. It requires enough of an effort to bring out the full ability of the student, and thus serves as an excellent means of measuring the student's capabilities.

5. It acts as a final test of the student's interest in a special phase of science and engineering, thus indicating for him whether he should or should not follow this special phase as his life work.

6. It brings the student into closer and more personal contact with those instructors who are specialists in the phase of engineering in which he is more interested. In other words, he gets to know better those members of the faculty he ought to know better.

7. It forces the student to plan his work so that it will be completed and ready for presentation on a specified date.

8. It makes the student use the full resources of the college and community, often encouraging him to cut across departmental and industrial barriers. It encourages him to use the full facilities of the library and to consult with experts in college and industry in order to obtain up-to-date and authentic information.

9. It gives the student practice in writing a report which will stand up under critical examination.

The Call of the Graduate School

At the end of the four-year curriculum, the student stands at the crossroads. To some, it is a terminal point in formal education. The desire to enter immediately upon a professional career and perhaps the pressure of economic necessity sends many of them immediately into industry. There are others who desire to continue their education in the Graduate School.

This desire to continue is not the only criterion which should be used by the Dean of Admission. In the Graduate School, we are looking for men with originality in thought, men capable of independent action. They should be, although they are not always so, the future leaders of thinking in the community.

Those men who have shown in the preparation of a senior thesis outstanding ability and originality are in a position to take full advantage of an opportunity to continue in graduate study and can, without question, be admitted to the Graduate School.

The faculty member who is called upon to approve such a student for admission has solid ground on which to base his approval. The student himself will enter on graduate study with a greater confidence in the knowledge of a previous job which has been satisfactorily performed. In the light of a long experience, the thesis preparation has been an unerring guide in the matter of eligibility.

Historical Addendum

The earliest theses still retained in the Library of the Institute were written by the class of 1855. Among others, A. F. deLacenda wrote on "Interoceanic Communication Through the Great Isthmus of Central America." With a somewhat prophetic vision of the United Nations, he concluded his thesis with these words:

"We have thus glanced over the more obvious reasons why no great ship canal without locks can be formed with any prospect of advantage to the world generally except on the Atrato and Cupica

(Colombia) line. Let us now conclude by expressing an earnest hope that the great maritime powers will unite in guaranteeing the political security and absolute neutrality of an undertaking so universally beneficial."

The design for the Brooklyn Bridge did not evolve from a graduation thesis. Washington A. Roebling of the class of 1857 wrote a thesis in 1857, some time prior to the construction of the bridge, but his thesis was the "Design for a Suspension Aqueduct," and Charles G. Roebling graduating in 1871, wrote on the "Design of a Parabolic Truss Railway Bridge." John Roebling had designed the bridge and Washington, his son, took over its construction on the death of his father.

G. N. Ferris of the class of 1881 did not design the Ferris Wheel for the Chicago Fair as a graduate thesis. His thesis was a Review of a "Wrought Iron Deck Bridge for the Boston Hoosac Tunnel and Western Railway."

We cannot say, of course, that the later success of any of these individuals was due to his graduating thesis. We can, however, claim that this experience contributed greatly to his development.

New Magic in Old Lines*

By ACHILLE PRESUTTI

Illustration Engineer, Technical Publications Staff, Jackson & Moreland, Boston, Mass.

For the engineer, efficiency is measured in economies of manhours, kilowatt hours, and British thermal units. The intangible quality of the efficiency of the artist, on the other hand, depends on his ability to inspire others by his appeal to their sense of beauty. So, formerly, while they met on the golf course and at social gatherings, the engineer and the artist had little in common in business matters. In spectacular fashion World War II brought the two professions together in a practical business relationship that bids fair to continue, now that peace has been attained. It makes for efficiency.

Under the lash of the War's demand for rapid production of military apparatus, able engineers and artists cooperated to prove that art could be an efficient hand-maiden to engineering, when it came to the production of mechanical drawings that were much easier to read than the standard orthographic puzzles that prevailed heretofore. So we have read much and heard more of the merits of *three dimensional* or *"visual"* drawings for the purposes of illustrating highly complicated machine assemblies, and of *exploded views* and *schematic representations.* The up-to-date engineer is avidly studying the pictorial methods because he realizes that industry will demand more and more applications of these efficient modern methods. You, who are training the coming generation of engineers, are, also, vitally concerned.

I hope, in today's talk, to tell a little of the methods by which this joint engineer-artist effort has been developed and to touch upon the fascinating future which American industry appears to promise in the field of pictorial, engineering drafting.

The pictorial methods take many forms, and we have found it convenient to classify them under the following headings:

Orthographic
- Black line.
- Colored line.
- Wash drawings.
- Diagrammatic.

Isometric or *Perspective*
- Pictorial black line.
- Pictorial colored line.
- Pictorial wash drawing.
- Schematic black.
- Schematic colored.

Retouched Photographs
- Minimum treatment.
- Full treatment.

I shall briefly describe our methods for each of the above types of illustrations.

* Presented at the fall meeting, New England Section, A.S.E.E., October 5, 1946.

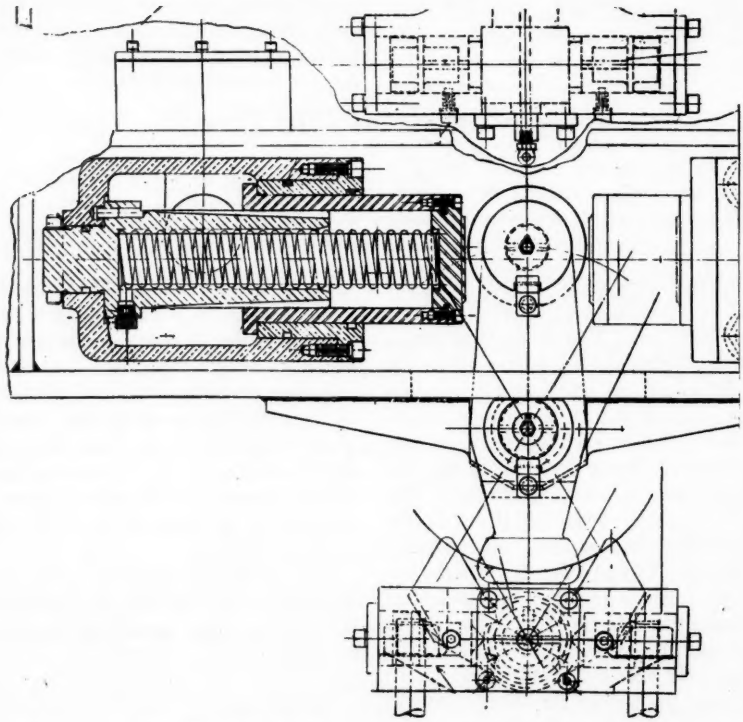


PLATE 1. Orthographic line drawing. A clear picture to the experienced mechanic, this view can be very puzzling to the apprentice mechanic. No credit.

Orthographic

There are many instances where orthographic one-plane views can be made to portray portions of the apparatus clearly and at considerable saving over the cost of the isometric or perspective types. *Plate 1* is taken from an orthographic shop blueprint. *Plate 2* is a photostat of this blueprint, which was handed to an artist, who, with air brush and hand brush, has given it the illusion of depth, thereby adding the third dimension at a minimum of expense.

Very simple mechanisms can be illustrated in orthographic lines only, dispensing with the services of the higher salaried artists. Orthographic line drawings are often satisfactory for schematic diagrams to show the flow and pressures of hydraulic fluid systems, particularly when the use of colors is permitted for the various conditions, such as "high pressure," "return flow," "tank pressure," etc. It is important in color work to allow the artist to select the colors, if displeasing "chromo" effects are to be avoided.

Isometric or *Perspective*

An isometric or perspective drawing is naturally more pleasing to the eye

than an orthographic view of the same subject. Here, under the watchful eye of the engineer to preserve design integrity, the artist can really do himself justice. Keen for accuracy, the experienced design engineer soon becomes enthusiastic, as he sees his brain child portrayed in such vivid self-explanatory fashion. Together, the engineer and artist will turn out pictures that are often truly impressive.

I shall take the pictorial wash drawing as my first example of this type. *Plate 3* is a three-quarter sectional view of a constant speed, variable discharge, hydraulic pump. I shall confine myself to the techniques involved in the preparation of a visual drawing of this apparatus, and shall not discuss the features of engineering design.

The first problem presenting itself is the angle at which to draw this pump so as to show to best advantage all of its important features. This is usually determined by a close study of the design assembly drawing. An isometric, trimetric or perspective is decided upon, depending on the depth and shape of the subject and upon which side of the machine contains the information that we desire to emphasize. One or two preliminary rough sketches in perspective are sometimes necessary to arrive at the correct angle.

We must determine how much sectioning is desired to reveal all of the

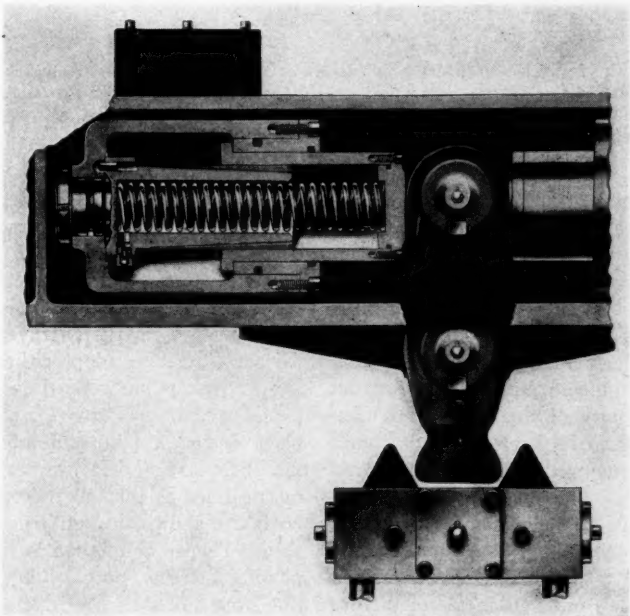


PLATE 2. Orthographic wash drawing. This drawing is merely Plate 1 after the artist has created the illustration of depth by skilful shading and highlighting—an inexpensive process. No credit.

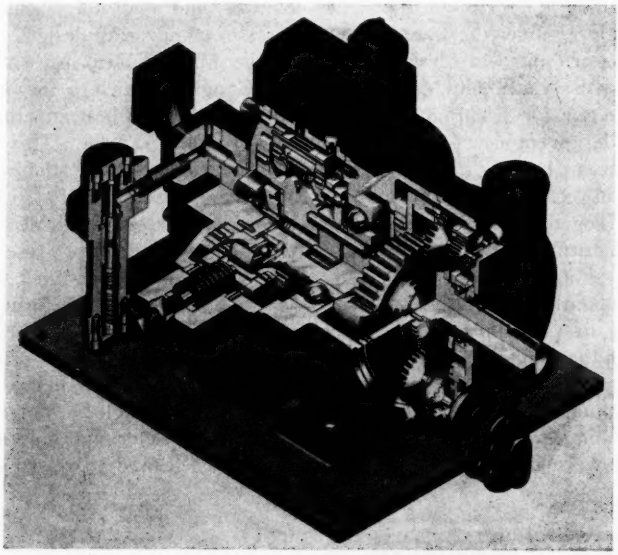


PLATE 3. Isometric wash drawing. In this cutaway drawing, just enough of the machine is removed to reveal important inside details without undue loss of the outside appearance. The complexity of the details to be shown warrant the higher cost, as compared with the simpler mechanism of Plates 1 and 2. (Courtesy Standard Machinery Co.)

component working parts and still retain a clear mental picture of the exterior of the machine. This also can often be settled by a few simple sketches, but, for complicated apparatus, considerable study is necessary which reflects the technical appreciation of the engineer plus the imagination and ingenuity of the artist-draftsman. The point to be kept in mind is that sections removed must be kept to a minimum. The cut does not necessarily have to be planar through the machine; that is, the section can be staggered to cut individual parts. In this manner, one gets a clearer picture of each part and it is also much easier to replace mentally the sections removed.

There are a few cases where this is not feasible, such as a drawing of a complicated valve block, with its many ports, pistons, and connecting passages for the hydraulic fluid, all of which must be clearly portrayed. Here, we are forced to adopt either of two alternatives. One is by the use of exploded sections (*Plate 4*), where the block is cut at points of interest and the slices are moved away along isometric lines so that all the valves and ports are shown in their true relationship. The other method is the use of phantom effects, or ghosting, wherein the front portions are given a transparent treatment to reveal the hidden parts, as shown in *Plate 5*, for a certain hand power device. These two

alternatives are used only when absolutely necessary, since we find that the average person can visualize the whole assembly most clearly in simple cutaway view.

When the drawing is completed in pencil, three ozalid prints are made. One is sent to the client for approval as to conception and treatment; one is given to the engineer in charge of the project for the engineering check as to function, also to satisfy himself that there is no inconsistency between his text and the illustration. The third print is given to the drafting checker who must make sure that the work is graphically correct, that it meets conventional drafting standards, and that it is clear, and free from the optical distortions of which axonometric drawings are sometimes guilty. As to this last point, the recent engineering college graduate appears to be better trained in the graphic technique involved in the making of axonometric drawings. I feel, however, that he would eliminate many hours of work revising his drawings and would require much less supervision had he also acquired a knowledge of the perspective. We find that

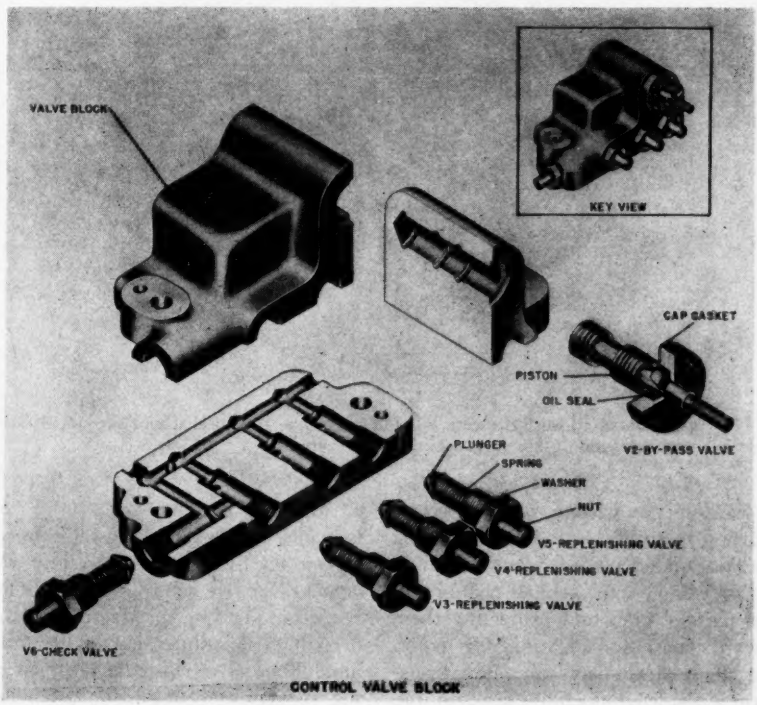


PLATE 4. Exploded section drawing. The many pistons and ports of the valve block would be difficult to show by other methods than the isometric displacement of the sections adapted in this view. No credit.

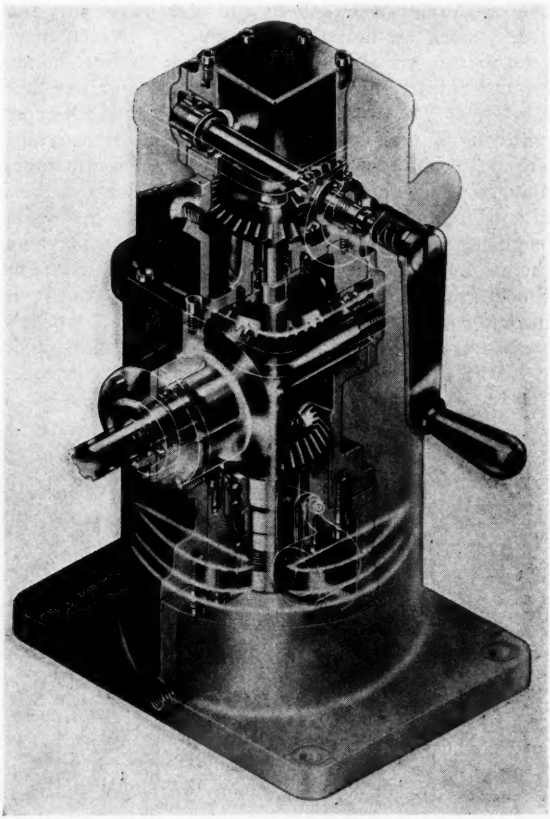


PLATE 5. Phantom wash drawing. If the housing of this mechanism were of glass this view indicates what the inside parts look like. No credit.

a working knowledge of perspective drafting is an absolute essential in the preparation of a good *visual* drawing. By the simple expedient of changing a few parallel lines and projecting them towards an assumed vanishing point, the clever draftsman can often transform a distorted assembly of parts into a realistic portrait of the subject.

When all approved changes have been correctly incorporated in the pencil drawing, a reduced photostat copy is made. Since the photostatic process allows us to reproduce to any convenient size, we arbitrarily set the first reduction at twice the size of the final, or publication dimension of the drawing. There are two main reasons why the reduction is not made all in one step at this stage. The first reduction is large enough to allow the artist and letterer to do good work. The final

reduction, made by the printer, tends to sharpen the lines by reducing any imperfection in the original.

After the photostat (first reduction) is mounted on a sheet of illustration board, the artist is ready to apply his "wash" rendering. This is done by the application of opaque water colors with the aid of the air brush and small hand brushes. The colors range from

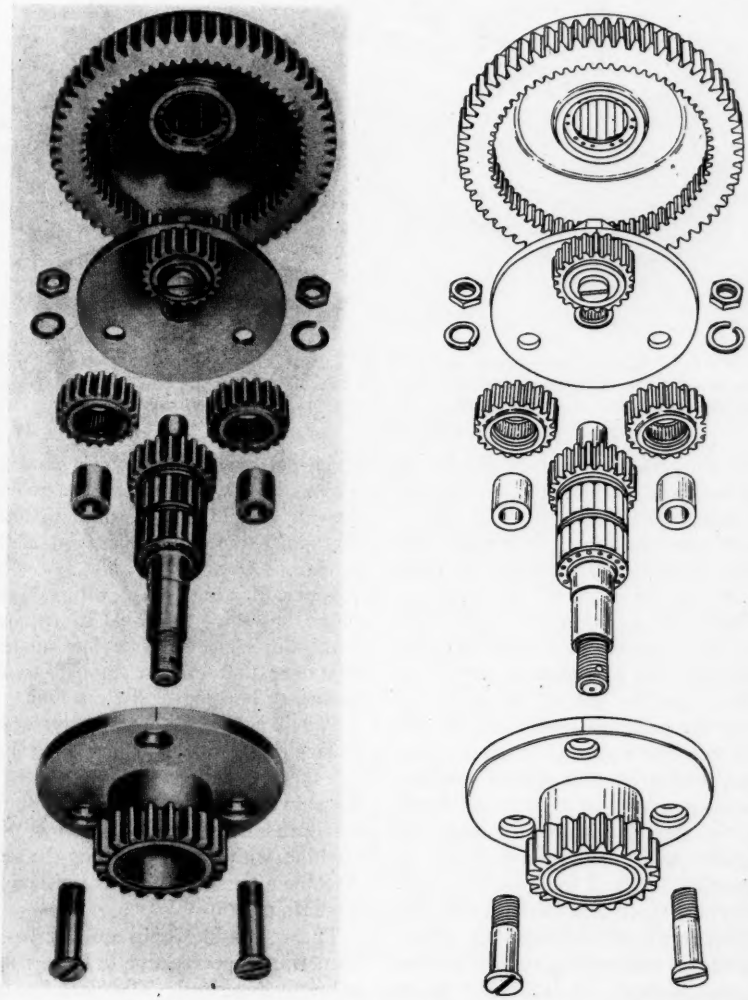


PLATE 6. Exploded view in line and wash. The "explosion" is controlled so that the parts land in just the right place, ready for the mechanic to pick up and put the gearing system together again. No credit.

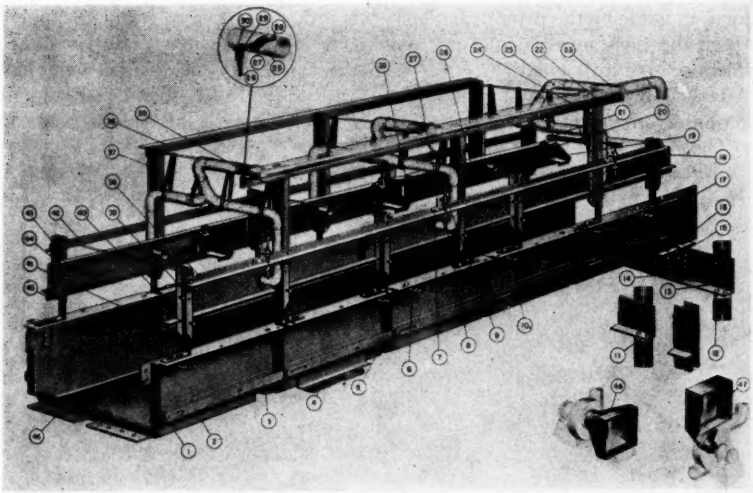


PLATE 7. Washed perspective with key to parts. This perspective will save many headaches for the installation and servicing mechanic. Quickly, he can locate each part, which the "parts list" describes in detail. (Courtesy Hartford-Empire Company.)

white through the various shades of gray to black. I find that, in spite of the numerous shades of grays available in pre-mixed form, it is often necessary to mix two or more to bring out the desired shade for a given tone.

The typical exploded view, shown in *Plate 6,* contrasts the line drawing treatment with the washed treatment.

Books on the subject of rendering advise the artist to strive to make his work look like a good photograph; they stress fidelity of tone to the machine illustrated. We, of course, all agree that we should portray a machine to resemble its actual appearance as far as possible. But, I feel that this wash rendering, three-dimensional idea can be developed still further. A photograph of an engineering subject is often flat and lifeless. It is limited in its scope. It tells us what a certain machine looks like. It does not tell us which parts move and which parts are stationary. I feel that the rendered drawing should also be used to bring out a machine's dynamics and statics in various contrasting tones. A shaft or gear with a high r.p.m. rating should gleam and shine to reveal its dynamic quality in contrast with the subdued treatment that can be applied to the stationary housing of the machine.

Plate 7 is a washed perspective which illustrates the use of balloons, to indicate the part numbers which the text of the catalog describes. *Plate 8* shows the draftsman's perspective view of a machine, with *Plate 9* showing the same machine after the artist has finished his rendering.

The remaining items on our list of isometric or perspective drawings may be briefly described. The *black line isometrics* merely depend on line work for their shading and highlighting; like-

wise, the *schematic* black or colored isometrics, while giving depths, do not have any wash treatment.

In our classification, we have arbitrarily agreed that a schematic drawing shows how apparatus works, that is, its functional processes, with an attempt to show the physical appearance of the parts. A diagrammatic drawing is a single-line representation of a system, which makes no attempt to indicate scale or physical appearance.

Retouched Photographs

Coming to the last item of our category of illustrations, the retouched photograph, it is obvious that the man responsible for illustrations must control the actual photographing of the machine and its parts. Much has been written of the skilled technique required in posing the apparatus, proper viewpoint, avoidance of distortion, and in lighting effects. Clever devices in the form of large and small adjustable

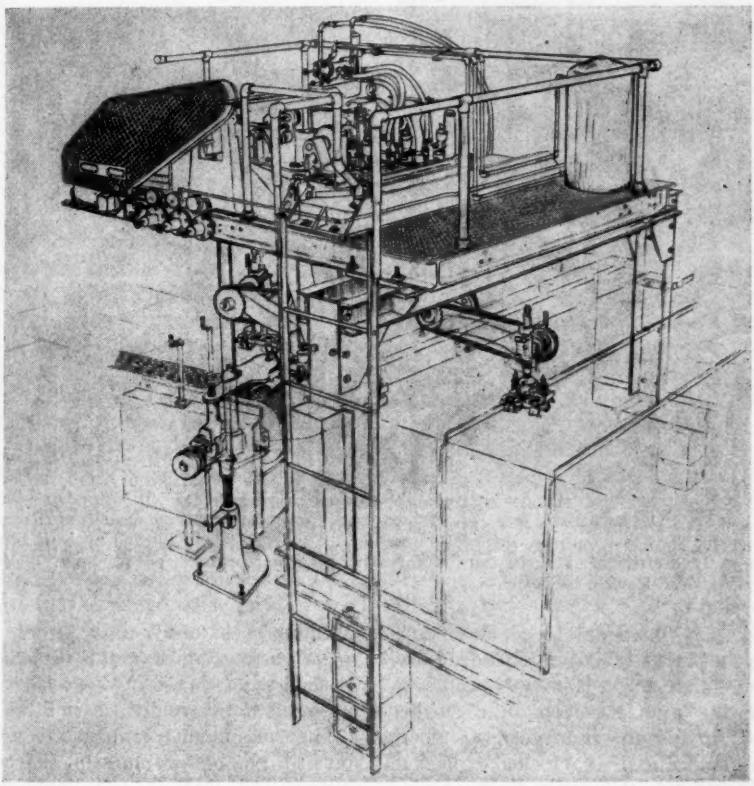


PLATE 8. The draftsman's part (wash drawing). The draftsman has studied 50 or more shop drawings (assembly, sub-assembly, and detail) of this complex machine. To a large scale, he has combined them into a single three-dimensional view. (Courtesy Hartford-Empire Company.)

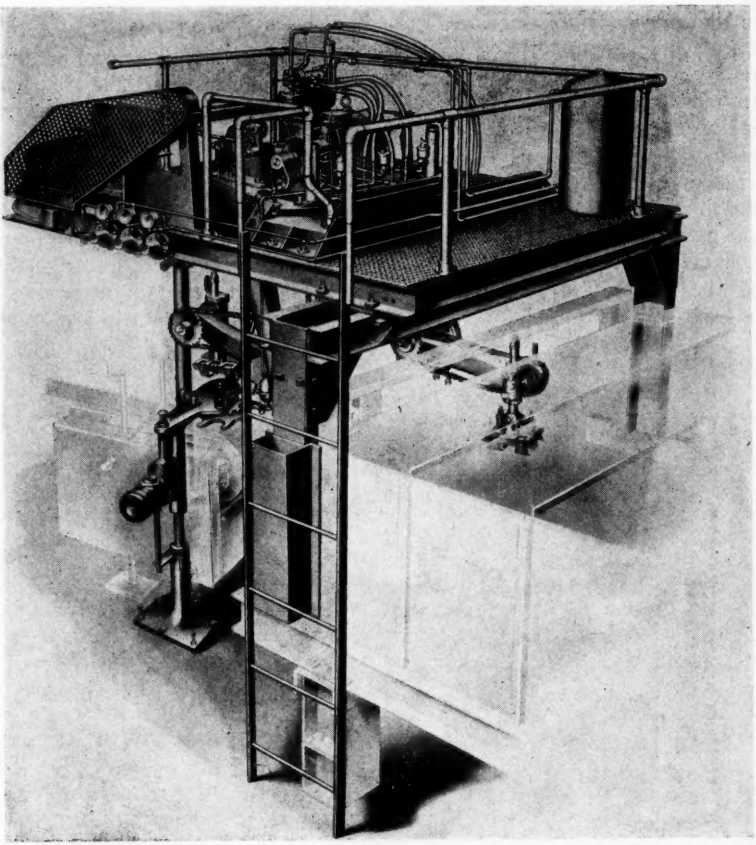


PLATE 9. The artist's part (wash drawing). This is another photostat of Plate 8, which the artist has outlined, shaded, and highlighted with his air brush and by hand brush. Magically, draftsman and artist can "photograph" a machine before it is even built. (Courtesy Hartford-Empire Company.)

racks have been developed for mounting the parts to make an exploded view. There are clamps, bolts, wax, and even chewing gum to mount the smaller parts in just the right position, where they landed in this controlled explosion.

Faithfully, the artist must remove defects, emphasize highlights and shadows, and sharpen outlines. He must avoid the temptation to dress up the machine; weld beads must be left in, rough castings must not be machine-finished by air brush . Above all, artificiality is to be avoided.

The "minimum treatment" of a retouched photograph merely sharpens outline and adds a few highlights. The "full treatment" entails the complete rendering of the photograph. The method to be used depends upon the

quality of the photograph that has been furnished and upon the general style of illustrations which has been adopted for the book.

Nomenclature

For illustrative drawings three types of lettering are used:

Free hand, rarely used.

Mechanical lettering, either Leroy or Wrico.

Type set—for which the printer composes the legend, using the desired font of type, and prints it on paper; the strip of paper being pasted on the illustration.

The finished book or catalog contains many pictures, the originals of which are of all sizes, requiring various reduction ratios to bring them all to the common dimensions which are required. Of course, the proper size of the original lettering for each must be selected. Hence, we have the problem of picking out in advance the proper template and pen to be used.

If the picture is a line drawing, the lettering is applied directly on it. For a wash drawing, however, with its large areas of solid black and various shades of gray, the printer must use a half-tone screen in the preparation of his photo-engraved plate, or his offset plate. Nomenclature for such a drawing is not executed on it. It is placed on a clear acetate overlay from which the printer makes a separate negative. This negative and the half-tone negative of the illustration proper are separately exposed on the same sheet of photographic paper thereby combining them into one photographic copy. Otherwise, leaders and lettering would appear dotted in the finished picture.

None of the illustrative products which I have described are new. I could show you handsome gearing perspectives in a portfolio dated 1857, and you could refer me to the sketch books of Leonardo da Vinci for three-dimensional views of his clever conceptions, centuries old. It is just that modern drafting and art equipment are different and that, during the past few years, the engineering profession has come to appreciate the merits of pictorial techniques. Great strides have been made and enormous quantities of such representations have been produced in this period.

Pictorial engineering drawings and pictures now have an established position in the fields of design, manufacturing, operation and maintenance. As a supplement to the orthographic type of engineering drawings, and often as a powerful competitor, the pictorial type has proved its merits.

The pictorial drawing is easier to read by skilled mechanics and it saves much time in the education of those who are unskilled. It is therefore an efficient implement in modern industry. Practicing engineers and those who are teaching engineering students are adapting their methods to include the techniques of pictorial drafting. The engineer and the artist have teamed up to demonstrate that, truly, there is magic in the old lines.

"Close-Coupled" Cooperative Engineering Education

By ALBERT SOBEY

Director, General Motors Institute

I suppose everyone who has had experience with Cooperative Engineering education appreciates the degree to which full effectiveness depends upon a carefully organized and directed work experience training in the plant as well as the curriculum of the instructional phase, and close coordination—or as our topic suggests, close-coupling between the two.

We have been fortunate, indeed, that our relationship to our cooperating plants has made it possible for us to have their full cooperation in both the plant and Institute phases of our Cooperative Engineering Program, with the result that it has been "closely coupled" and, as I said, I shall be very glad indeed to share with you anything out of our experience that might be interesting and helpful to you in your work.

To indicate to you, as engineering educators, the real significance of our experience in this program, however, it is necessary first of all to picture for you its relation to the purposes and objectives of this institution in its capacity as the central agency in education and training for the Corporation and the engineering approach which we have made to the educational and training needs and problems of its various organizations.

We hear references from time to time to Human Engineering in Industry. Accepting that term for what it usually implies, the field of service of the Institute might be defined as that phase of Human Engineering in Industry which deals with the development of people in and for industrial organizations so as to meet their operating problems effectively and provide the basis for progress.

In fact, since American industry and its service to American people represent an achievement of men and women and since every aspect of its current operations and its possibilities for future progress depend upon their creative ability and productive efforts, the basic premise of General Motors Institute is that industry's first and most vital task is the development of its people in and for its operations.

Furthermore it is equally vital to organize within the industry in such a way as to release and utilize effectively the capacities and abilities thus developed to serve their own and the public good.

The schools and colleges, of course, play an important and greatly appreciated part in providing industry with youth of future potential for its organizations. They also can, and in many cases do, make constructive contribu-

tions to members of the existing organization.

Those of you who were present at the 25th Anniversary of the Institute will recall, however, that it was pointed out very clearly that industry must accept the responsibility to develop its "end product" in personnel in order to have available and to utilize the abilities and understanding required to carry forward its specific operations cooperatively and effectively.

The importance of this to our industries and to our American people can hardly be overemphasized.

We are all familiar with the war experience and how, under the stimulus of the common objectives of the war emergency, American industry was able to so marshal, develop, and utilize the capacities and abilities of its people as to perform a virtual miracle of war production which made possible the winning of the war. Everyone intimately conversant with the situation, however, knows that from an engineering standpoint only a percentage of what was really possible was accomplished.

In view of the troubles experienced since V–J Day and the obvious problems ahead, the importance of making sound progress in the discharge of this responsibility presents a challenge in Human Engineering to Industry fully as great as any engineering problem in Product or Manufacturing, and from some standpoints much more vital.

The meeting of this challenge depends, of course, upon the technical and executive leadership provided at all levels of the organization, from top to bottom. Hence the development of this leadership is the most important part of industry's first task.

This indicates to you, then, the basic field of service of this institution, for it is to contribute to this task that the Institute is dedicated. While we participate in almost all types of training, the main objective of General Motors Institute is to contribute to the development of the executive and technical leadership required for the current operations and future progress of General Motors.

When you analyze this over-all task of the Institute, it divides itself into two main branches.

1. Education and training required for the development of present members of General Motors organizations.
2. Education and training required for the induction into the ranks of General Motors of young men of potential and with sound foundations, both technical and practical, for development for future leadership positions.

To satisfy the first requirement a very extensive program has been developed that reaches thousands of General Motors people each year, but this is somewhat apart from our theme of this evening.

The Cooperative Engineering Program provides the Institute's main contribution to the second. This contribution, of course, is only part of the whole, for it is recognized that sound progress in organization requires that channels be kept open for leadership potential from all ranks and all available sources, and we do participate in various ways in other programs designed to keep these channels open, including the college graduate programs for graduates of your institutions and other colleges and universities throughout the country.

Incidentally the Cooperative Engineering Program has had an important

supplementary value in that it has provided a "steady productive load" which has made possible building and maintaing the organization required to deal effectively with all the varied educational and training needs of the Corporation.

Before outlining for you our experience in this Cooperative Engineering Program I should refer briefly to our program research and development because it is so typically engineering. We have recognized that to make real progress in the development of leadership for all the various fields of the industry requires an emphasis upon improvement of educational and training methods similar to the emphasis upon research and engineering in the improvement of products which has brought such progress in that field.

Accordingly the Institute has made a constant effort to apply a sound research approach to the various problems presented to it by the organizations it serves. It also provides a central agency through which is pooled the best thought and experience of the Corporation in this field to the end that improved methods and materials may be developed and made available to all the divisions. This has been a major factor in the development of the Institute program.

Turning now to the Cooperative Engineering Program, I shall briefly review for you some of the more significant features in its development and in our experience in over twenty years of its operation. I shall then indicate how our efforts to improve the program led to the development of the new Fifth-Year Continuation Program and our experience so far in its functioning.

As I have indicated, the original four-year Cooperative Engineering Program was designed to provide one source of young men of potential with an engineering and practical foundation for future positions of leadership.

From the beginning, emphasis has been placed upon capitalizing the unique relationship existing between the Institute and the cooperating organizations and to pool the knowledge and experience of executives, scientists, and engineers of the Corporation with the knowledge and experience of the Institute faculty in the development and improvement of this program.

An interesting factor in this connection is that the thirty members of the Board of Regents each of whom is in charge of a major division of the Corporation's activities, are among the principal users of the graduates and therefore have an opportunity to compare and test results.

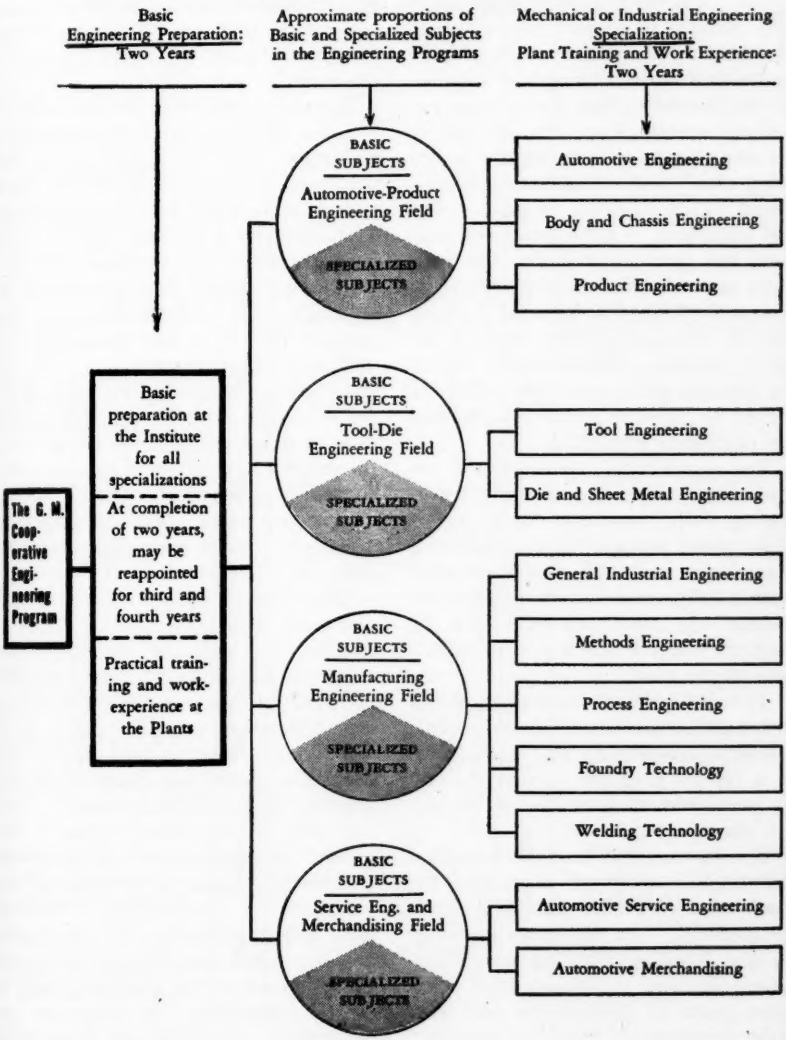
The Cooperative Engineering Program has three parts which might be considered as three curricula. They are

1. The engineering instruction program conducted at the Institute.
2. The organized work experience training program at the plants, and
3. A series of industrial and technical reports coordinating the Institute and plant phases of the program.

The engineering instruction program consists of two years basic engineering required of all students and two years of mechanical or industrial engineering specialized in several fields, and designed to prepare the student for future responsibilities in corresponding branches of the operations of the Corporation.

This is indicated in graphic form by the attached chart which shows the first

THE GENERAL MOTORS FOUR-YEAR COOPERATIVE ENGINEERING PROGRAM


Basic Engineering Preparation: Two Years
Approximate proportions of Basic and Specialized Subjects in the Engineering Programs
Mechanical or Industrial Engineering Specialization: Plant Training and Work Experience: Two Years
The G. M. Cooperative Engineering Program
Basic preparation at the Institute for all specializations
At completion of two years, may be reappointed for third and fourth years
Practical training and work-experience at the Plants
BASIC SUBJECTS
Automotive-Product Engineering Field
SPECIALIZED SUBJECTS
Automotive Engineering
Body and Chassis Engineering
Product Engineering
BASIC SUBJECTS
Tool-Die Engineering Field
SPECIALIZED SUBJECTS
Tool Engineering
Die and Sheet Metal Engineering
BASIC SUBJECTS
Manufacturing Engineering Field
SPECIALIZED SUBJECTS
General Industrial Engineering
Methods Engineering
Process Engineering
Foundry Technology
Welding Technology
BASIC SUBJECTS
Service Eng. and Merchandising Field
SPECIALIZED SUBJECTS
Automotive Service Engineering
Automotive Merchandising

two year basic program, the major third and fourth year sequences and the specializations within those sequences.

The plant work schedules are carefully planned in advance for each pair of students each year so as to provide sound experience training and to parallel the Institute phase of the program.

Considerable effort was exerted in the early years of the program to develop ideal work schedules to be followed by all students in given years and sequences. Our experience, however, has demonstrated that the variables are so numerous that individual programs planned in advance for each pair of students provide the most effective results. The schedules resulting from the early work, however, have served as valuable guides in planning the individual schedules.

The cooperative students are required to write a coordination report during each four-week work period. This report program is also definitely planned for each pair of students each year in advance, and is designed to coordinate the instruction received at the Institute with the practical work experience at the plant.

The way in which these three phases knit together to form a "close-coupled" whole is indicated by this chart which is a typical program carried through by one of the students during his senior year.

The Institute has been fortunate that the large number of applicants has made its selection for admission highly competitive. The applicants are rated by the Institute from an educational standpoint and the plants then select their quota of students for each year from the approved list. The men thus selected are entered as employees of that organization in training for future responsible positions in its operations.

All other factors being equal, the plants in selecting their students give preference in this order: first, to present employees; second, to members of employees' families; third, to young men in the plant city; and fourth, to all others.

Beginning students are admitted to the program for only the first two years and must qualify for reappointment for the third and fourth years by their records at the Institute and in the plant. The Institute, the plant, and the student all participate in this decision. This two-plus-two plan has proved to be much more constructive than the original plan of a four-year program with a two-year terminal.

It also has another advantage. Under the original plan it was frequently difficult to get the plant to decide with the student as to the field of operations for which he was to be trained during the last two years. Now, to reappoint a student a plant must make this decision and indicate it to the Institute.

The student's program for the next two years is then directed by the head of that branch of the division. The work schedule, the specialization in the Institute courses, and the coordination report program are then designed to provide the training and experience needed to qualify for a significant beginning job in that field of work. This has been an important factor in the general effectiveness of the program.

A definite follow-up program of the graduates is maintained. Surveys with both management and graduates are conducted annually to determine the progress of the graduates and to obtain suggestions for program improvement. Many valuable suggestions received annually become cumulative in their indications of avenues of sound program development.

A TYPICAL SCHEDULE SUBMITTED FOR A STUDENT IN PROCESS ENGINEERING—DURING HIS FOURTH YEAR

WORK SCHEDULE FOR FOUR-WEEK PERIODS AT THE PLANT	COORDINATION REPORTS, WRITTEN AT THE PLANT, COMBINING ENGINEERING INSTRUCTION AT THE INSTITUTE WITH PRACTICAL EXPERIENCE FROM THE PLANT	INSTITUTE COURSE FOR FOUR-WEEK PERIODS AT THE INSTITUTE
FIRST SEMESTER	**FIRST SEMESTER**	**FIRST SEMESTER**
1. Process Engineering—Assisting Hydraulic Engineer	1. Hydraulics Applied to Mechanical Tools and Products	Process Engineering
2. Process Engineering—Detailing in layout, Installing, Maintenance	2. Fundamentals of Time Study	Methods—Micromotion Study Manufacturing Costs Production and Quality Controls
3. Methods and Time Study—Assist Methods and Time Study Engineers	3. Reason and Purpose of Time Studies	Nomographs: Special Slide Rules Principles of Psychology Directed Readings in Current Problems Employment Relationships
SECOND SEMESTER	**SECOND SEMESTER**	**SECOND SEMESTER**
1. Methods and Time Study—Assist Methods and Time Study Engineers	1. Direct Application of Material and Labor to Cost	Process Engineering Methods Planning—Time Study Manufacturing Costs
2. Accounting—Labor costs, burden rate, financial statements	2. Burden Development and its Application to Cost	Personnel-Management Controls Economics of Tools and Equipment Applied Psychology
3. Accounting—Labor costs, burden rate, financial statements	3. Coordination Report omitted for last month of 4th year	Directed Readings in Current Problems Coordination

Coordination Conferences composed of Institute faculty and the Corporation executives responsible for the plant phases of the program are held annually, and sometimes more frequently, to consider the experience to date and to formulate plans for an improved program for the next year.

Over the years this Cooperative Engineering Program has been referred to as "a significant experiment in Engineering Education because of its setting, its freedom of action and intelligent experimentation in program development, and its close relationship with modern industrial practice."

The record of the graduates, which after all is the test of an educational program, has demonstrated quite positively we feel the soundness of the experiment. Prior to the war over 90 per cent of the graduates, some 1,500 in number, remained with the Corporation and of these 93 per cent on the average were rated *very good* or *good* in the annual graduate surveys. The number reported unsatisfactory has been consistently very small—only 3/10 of 1 per cent in the last full pre-war report, for example. Equally significant, 65 per cent of the graduates whose classes have reached the ten year point have qualified for the Ten-Year Graduate Key, meaning that they are with the Corporation in responsible charge of the work of others or have equivalent technical responsibilities.

Naturally, since such a large percentage of the graduates remain in General Motors and hence, as it were, on "the Institute's doorstep," this relatively favorable record has been most fortunate. In fact, we feel we have been very fortunate in our graduates.

The war emergency, however, presented the vital test of the entire program. The graduates were called upon to meet new and rapidly expanded responsibilities with reference to new products and methods in the conversion to war production. They were also called upon in relatively large numbers to compete—or at least be subject to comparison—with graduates of other engineering colleges and universities upon entering the Armed Services.

Students in the enlisted reserve program at the Institute were transferred to other colleges in Army and Navy A-12 and V-12 programs and in many cases subjected to question by both other students and faculty because the Institute did not, as a matter of policy, grant degrees even though empowered to do so since the original charter was received from the state in 1927–28.

The record throughout has been very encouraging as I believe you know. The contribution to the Corporation's war conversion program was very considerable. In fact, Corporation leaders have frequently said to me that the Institute graduates were a vitally important factor in making the Corporation's conversion record possible, and even that the conversion record would not have been possible without them.

In the armed forces the record was equally creditable as was that of students transferred to other colleges. In fact, voluntary letters of congratulation were received from other colleges on the record of transferred students, the most striking, perhaps, from Yale where twenty-five of our students were transferred at the end of their junior year into the senior year of the V-12 Program and finished with records that brought three of these letters.

One fact that pleased us greatly was that these letters referred to the character of these men, their ability to work, and their evidence of potential

leadership as well as to their technical ability. Recognizing the need for leadership based on a practical application of Christian principles, we have aimed to develop young men of sound character as well as good engineers.

I mention these facts to give you some indication of the results that have been obtained from this "close-coupled" Cooperative Engineering Program and also to provide a background for a brief outline of our experience in our latest advance step to which I shall now refer.

As I have previously indicated, we have recognized over the years the need for constant emphasis upon program development. We could hardly continue to function in the dynamic automotive industry and in General Motors if we did not.

In this connection we have been interested in the possibilities for improvement of the transition from student status to engineering employee status upon graduation.

In this, of course, we have not been alone, for we understand the degree to which this period of transition from college to work has been recognized as a difficult one and know something of the many things that have been done to help the young graduate make that transition more effectively, including, for example, the introduction of the professional orientation course into the curriculum at the University of Detroit so interestingly explained this afternoon.

We have made corresponding efforts in our regular four-year program and along with this had been giving attention in the years prior to the war to some form of continued experience training combined with continued technical development in the year following the completion of the four-year program. We were not too successful in this for a number of reasons, and the efforts were abandoned during the war.

Following the war and implemented very largely by our war experience the efforts were resumed and resulted in what we have called the Fifth-Year Continuation Program of engineering project studies and work experience which was initiated with the graduates of the 1945 class last August.

The program has been very carefully developed by the faculty working with a special committee of the Board of Regents and was checked with several engineering educators from other institutions before being put in final form and approved. In fact, I should like to recognize at this time the interest and the valuable reactions and suggestions received from Dr. Wickenden, President of the Case School of Applied Science, and Dean Crawford of the University of Michigan, and also from Professors Leutwiler of the University of Illinois and Elliott of the University of Wisconsin who came to us as an advisory committee through the very constructive interest and cooperation of the E.C.P.D.

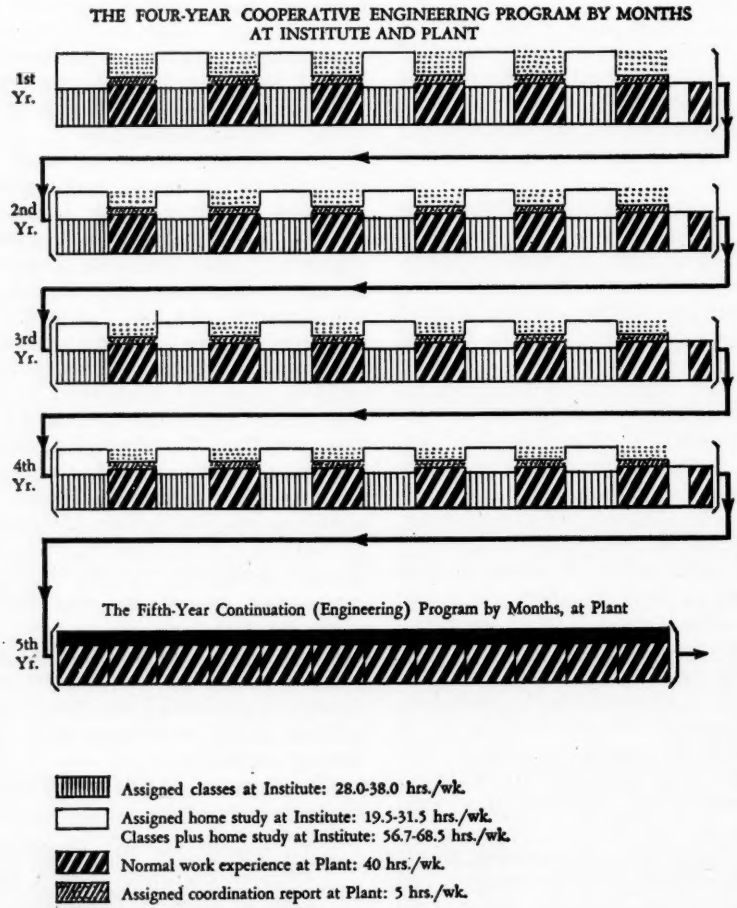
It has been a very stimulating experience to develop this program and direct it so far, and I am certain you will find a brief review interesting and possibly suggestive.

The objective of this Fifth-Year Program is two-fold.

1. To provide for an orderly and effective transition from a program of directed development to one of self-development, and from a student status to that of an engineering employee.
2. To provide opportunity for the student to broaden his training,

A FLOW CHART

SHOWING THE RELATIONSHIP OF THE FIFTH-YEAR CONTINUATION (ENGINEERING) PROGRAM TO THE FOUR-YEAR CO-OPERATIVE ENGINEERING PROGRAM (BASED ON NORMAL CONDITIONS)


THE FOUR-YEAR COOPERATIVE ENGINEERING PROGRAM BY MONTHS AT INSTITUTE AND PLANT
1st Yr.
2nd Yr.
3rd Yr.
4th Yr.
The Fifth-Year Continuation (Engineering) Program by Months, at Plant
5th Yr.
Assigned classes at Institute: 28.0-38.0 hrs./wk.
Assigned home study at Institute: 19.5-31.5 hrs./wk.
Classes plus home study at Institute: 56.7-68.5 hrs./wk.
Normal work experience at Plant: 40 hrs./wk.
Assigned coordination report at Plant: 5 hrs./wk.
Review of engineering studies, at Plant
Assigned fifth-year project home studies at Plant: 12 hrs./wk.

demonstrate his engineering ability and his capacity to assume responsibility, and to be evaluated by his employer under a continued work experience program.

The program as organized consists of two parallel and coordinated parts.

1. Project studies designed to broaden his technical training and enable him to apply previously gained engineering knowledge.
2. A work program designed to broaden his experience in the area for which his cooperative engineering training has prepared him.

The project studies are composed of actual problems in the area of the student's work assignments and are of such a nature as to be of importance to current or future operations of the Division. They, therefore, have a practical significance in the student's field of work and provide a test or measure of the student's engineering ability.

The relationship of the Fifth-Year Continuation Program to the preceding four-year Cooperative Program is indicated by this flow-chart in which are indicated the relative time requirements of the Institute and plant phases of the four-year cooperative program and also the full-time employment of the student during his Fifth-Year Program and the time requirement for his "home-work" on his project studies.

The organization of the program from an operational standpoint has also been carefully worked out as is indicated by this chart.

Plant committees for the administration of the program are appointed by the plant managements and the corresponding Institute committee by the Institute administration. The plant committee assigns the projects to approved students at their plant in consultation with the student and subject to approval by the Institute committee. The plant committee then appoints for each student a plant project adviser who is familiar with the field of the project study and interested more or less directly in its solution. The Institute committee appoints a project supervisor for each student. For his work program the student reports to his supervisor in his department organization who may or may not be his project adviser.

To qualify for this Fifth-Year Program, the applicant must have successfully completed the four-year Cooperative Engineering Program of the Institute and must have the approval of his cooperating plant or divisional committee.

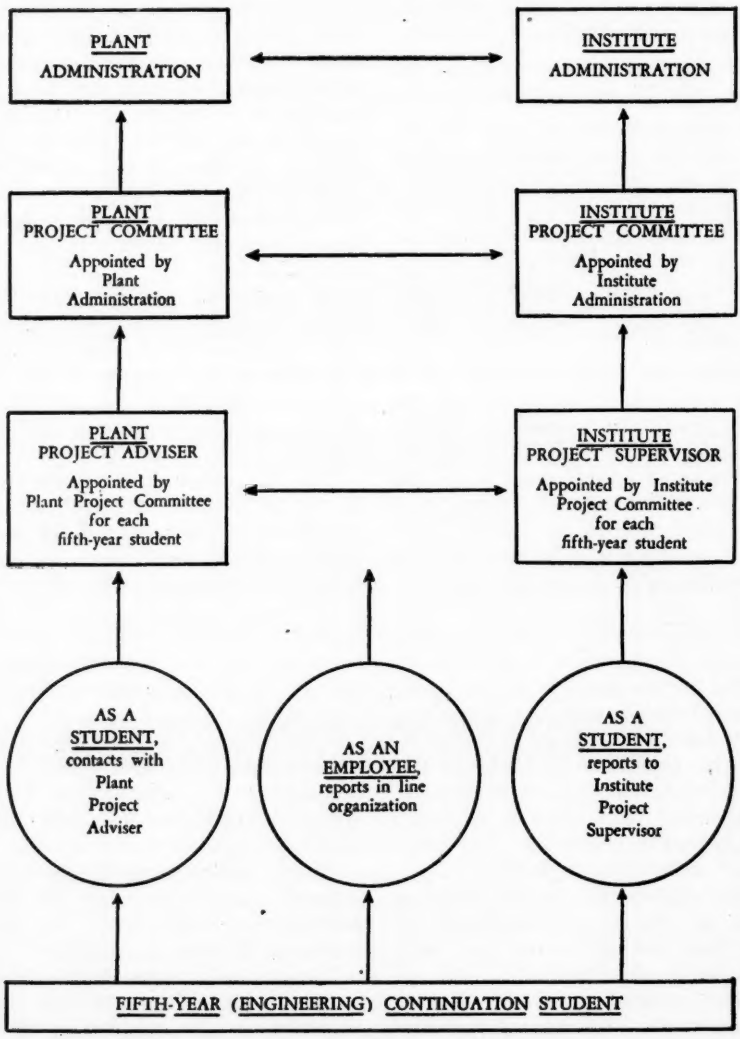
The fifth-year students have been expected to assume initiative and responsibility for completing all the plans, project outlines, and details for their Fifth-Year Program, subject, of course, to necessary approvals. In this the student's approach and his attitude combined with his ultimate findings in his project studies will determine his final rating.

The student is required to make a report monthly or more frequently, if necessary, to his supervisor at the Institute and his adviser at the plant upon his progress in his project studies.

He also makes monthly a work experience report approved by the plant representative with copies to plant management and to the Institute.

The graduating class of 1945 was a small one due to the war and the large percentage of the original enrollment serving in the Armed Forces. As a result there were just twenty-one graduates who qualified originally and entered upon the program. One was

OPERATION OF THE FIFTH-YEAR CONTINUATION PROGRAM



forced to drop out early due to serious illness, and another for personal reasons. A report for the remaining 19 was prepared and is available here if you are interested. The report gives the name of the student, his project, name and position of his plant adviser, name and department of the Institute supervisor, and the names and positions of his plant project committee.

	Project	Plant Adviser	Institute Supervisor
Lawrence Boyd, GMC Truck and Coach	Special study of Heating and Ventilating of Plant 2	Don Neal, Ass't Plant Engineer	L. B. Wocholski, Science Department
Walter Kauppila, Fisher-Lansing	Glass Breakage Control in Auto Body Manufacturing	E. L. Kollmorgen, Prod. Standards Superintendent	O. F. Whipple, Ind. Engineering Department
Jordan S. Sobel, Saginaw Steering Gear	Torques Necessary to Steer Automobile Wheels under Static Conditions	C. W. Weedfall, Senior Engineer	E. K. Harris, Auto Eng. Dept.

You would naturally question the effect of the strike which came so soon after the beginning of the program. We too questioned its effect and promptly called a conference of all the students concerned together with their advisors to meet with the Institute supervisors and project committees, at the Institute.

This proved to be a very fortunate step, for the conference not only resulted in the formulation of plans for meeting the strike problem, but also proved so constructive in clearing up questions regarding the mechanics of the program and establishing a clear understanding of the relative responsibilities of students, advisers, and supervisors that the conference has now become part of the normal program procedure.

A mid-year conference of all the students in the program together with their advisers and supervisors was held on February 11. Bringing together these "triple teams"—students, advisers, and supervisors—to check the student's progress to date and to lay plans for carrying his work forward to completion and then pooling experience in a general conference has proved most constructive in maintaining the program on a high plane.

These conferences, of course, are in addition to contacts by Institute supervisors at the plants and student contacts at the Institute for consultation and advice. These plant and Institute contacts follow no regular schedule, but are on an "as needed" basis.

Year-end conferences are planned for all students at the Institute in July and August to evaluate their finished project reports and test their knowledge of their subject and their understanding of the Engineering field involved.

The program has now progressed to a point where it is possible to make a relatively accurate appraisal of results with this initial class.

Frankly the program was somewhat more difficult to administer than at first appreciated, but the record to date is quite promising. The cooperation of the plant and divisional managements and the men assigned to the plant com-

mittees and as project advisers has been excellent. The men appointed to the committees have been well chosen. The projects assigned, with adjustments in some cases, have proved to be splendidly adapted to the basic objectives of the program and the advisers are well informed and interested in the area of engineering involved. This was, of course, essential to the success of the program.

The reaction of the plant managements and men directly involved in the program as it has progressed has been favorable indeed. This was very apparent at the mid-year conference, for example, and in the way in which the extension of the program to the mid-year class of March and April was received and acted upon.

The Institute committee and project supervisors have, of course, cooperated very well and one of the interesting by-products of the program is found in the values that are accruing to the faculty from the contacts with the work of the students in their projects and with the project advisers.

The students, in a number of cases, got away to a somewhat shaky start. As a new, untried program, greater demands were made on the students from the standpoint of the exercise of individual initiative and independent analysis of their projects and action with reference to them than had been anticipated. Steps were taken to meet this situation and the programs has been moving forward as planned.

Of the 19 in the program, our latest progress reports indicate that 5 will finish with very good records, 5 with good records, 4 with fair records, and 4 may not finish satisfactorily. This accounts for 18. The remaining man did not do the work, and has been dropped from the program. This overall result is about in line with our expectations.

Turning now to values received and the extent to which the program is meeting its basic objective, the record is also favorable. The values to the student are unquestioned even in the cases of those who do not promise to finish satisfactorily. Their transition to the work areas to which they have been assigned has been facilitated. They have had a real opportunity to apply their engineering knowledge and ability to well-selected practical problems of direct importance in their field of work and to demonstrate to themselves and their managements their capacity and ability to deal with them and, fully as important, the "shortages or lacks" that they must overcome. Along with this and possibly most important, they have had their horizons broadened and have gained a positive indication of the initiative and effort required of them as individuals to make real contributions to their profession and resulting progress for themselves.

The direct contribution to the plants through the project work is not so uniformly on the positive side. In some cases real contributions are being made; in other cases the results are "interesting." In one case at least the results so far are negative—a demonstration of what not to try, which, in itself, is also constructive. However, this side of the situation does not seem to concern the plant managements. To them the results are positive to the degree that the program provides sound development for the student and reaches its basic objective which is their first interest.

Hence to summarize—the program in this first year of operation has proved sound in concept, the mechanics have been well organized and carried for-

ward, and the values accruing to the students indicate that its basic purpose and objectives are being reached.

This leaves one further point that I should report to you, and that is the part that incentives have played in the record that has been made. One of the big reasons why the efforts made along this line before the war did not succeed was that there was not a sufficiently strong incentive to offset the handicaps of other conflicting interests and demands upon the student's time.

The war experience opened up the possibility of supplying the incentive. During the early part of the war it became clearly apparent that graduates of the Cooperative Engineering Program were being handicapped in their service to the war effort by the Institute policy of not granting degrees. Fortunately this handicap was overcome by the caliber of these men as demonstrated to the Armed Forces. The effect, however, was to greatly intensify the demand, which has existed over the years from the beginning of the program, that the policy be changed and degrees granted. Furthermore, this demand was intensified against the background of this early war handicap. This was an important factor since the policy of the Board of Regents has always been to serve the best interests of the students and graduates.

Hence the stage was set. In view of the graduate record, it was natural that the initial demand was to grant degrees for the established program, but when the values that would be added by the Fifth-Year Continuation Program were appreciated, the wisdom of adding the requirements of this additional year and using the degree to provide appropriate recognition and the needed incentive to make the Fifth-Year Program successful became apparent.

Thus, with this extension to the Program, the Institute rounds out and completes its service to its engineering students and at the same time conforms to the general pattern that has now been accepted by cooperative engineering colleges throughout the country by adding the Fifth-Year requirement. With the additional work, the students are enabled to acquire over the five-year period standard academic credits commensurate in number to those normally required for the Bachelor's degree without taking into account the values derived from the work experience training in the plant.

Recognizing as we do that in the last analysis the real measure of any educational program is found in the results achieved by its graduates, the new extended program s h o u l d f u r t h e r strengthen and expand the outstanding results that have been obtained over the years so far by the graduates of the four-year Cooperative Engineering Program.

In approving a year ago the initiation of the Fifth-Year Program, the Board was conservative and deferred definite action with reference to the degree pending actual experience in its use. The Board did indicate, however, that if the students in the first class demonstrated that they could carry the program through successfully, they would take definite action when this result had been achieved. In view of this and the obvious success of the program, as already reported to you, the Board of Regents has just taken action approving the granting of appropriate Bachelor's degrees at the Commencement next August to those men who successfully complete the requirements of the Fifth-Year Program.

To summarize, then, this is what we really have done:

1. We have set up the Fifth-Year Continuation Program to broaden the student's engineering training and experience and to contribute to a more effective transition from student status to that of a full-time engineering employee and from a program of directed development to one of self-development for our Cooperative Engineering students.
2. To accomplish this purpose we have made application of three recognized educational procedures.
   a. The internship—in the continued work experience training in the plants during the fifth year.
   b. The thesis—on a very practical basis in the project studies.
   c. The degree—to provide appropriate recognition of scholastic and professional achievement and the needed incentive to make the program effective.

We recognize, of course, that this is our first model in this program and that it is not perfect. Improvements have already been made and undoubtedly will continue to be made as we gain further experience, but so far, as I have reported to you, we are very much encouraged with the way in which these applications of these three procedures are contributing to our objectives.

We were somewhat surprised to have one of the engineering educators with whom we conferred indicate that our experience in this program might make a significant contribution to engineering education. If it does, we shall, of course, be very happy, but in any event we are convinced that it is adding very real and significant values to our Cooperative Engineering Program and to its graduates.

This then is the rather intimate review, as requested by your committee, of our experience in this "close-coupled" Cooperative Engineering Program and the way in which it contributes to the personnel development program of General Motors Corporation.

We are sincerely trying to fit into our niche, develop a program to meet our specific situation, and render the maximum service possible to our students, the Corporation, and in that way to the people of the State and Nation.

Employment Histories of Engineering Graduates*

By EVERETT D. HOWE

Assistant Dean, College of Engineering, University of California

Employment after graduation is the chief incentive for the study of engineering. The type of employment actually obtained and the success achieved therein are dependent upon many factors, among the more important of which are personal characteristics, the degree of technical competence and the general economic and employment conditions which obtain at the time of graduation. The primary aim of an engineering curriculum is to develop a satisfactory degree of technical competence for the type of work in which the individual is likely to become engaged.

In connection with its recent studies of the curricula being offered, the College of Engineering at the University of California at Berkeley decided to survey its graduates to determine the principal types of work which had been obtained by them. Accordingly a questionaire was formulated and mailed to some 3,000 graduates who had received degrees in the 23 year period between 1920 and 1942 inclusive and whose present addresses could be obtained. Approximately half of the questionaires

* Presented at the 54th annual meeting, S.P.E.E., St. Louis, June 20–23, 1946.

TABLE I

DISTRIBUTION OF REPLIES BY CLASS YEARS

Class Years	C.E.		E.E.*		M.E.		M. & M.		Totals	
	Degrees Awarded	Replies Rec'd	Degrees Awarded	Replies Rec'd	Degrees Awarded	Replies Rec'd	Degrees Awarded	Replies Rec'd	Degrees Awarded	Replies Rec'd
1920	13	4	**	5	**44	3	16	5	73	17
1921, '22, '23	71	12	**	16	*155	14	73	21	299	63
1924, '25, '26	99	16	**	56	*326	28	96	21	521	121
1927, '28, '29	124	35	**	49	*299	30	75	16	498	130
1930, '31, '32	187	52	**	33	*278	36	47	10	512	131
1933, '34, '35	162	45	183	68	183	48	67	26	595	187
1936, '37, '38	207	73	219	80	260	91	105	49	791	293
1939, '40, '41	251	101	257	85	356	149	173	67	1,037	402
1942	194	15	192	45	346	70	84	21	816	151
Totals	1,308	353	851	437	2,247	469	736	236	5,142	1,495

* These figures include degrees in both M.E. and E.E.
** Degrees in E.E. included with those in M.E. for these years.
C.E. = Civil Engineering.
E.E. = Electrical Engineering.
M.E. = Mechanical Engineering.
M. & M. = Mining and Metallurgy.

were returned by the graduates, the distribution between classes and curricula being given in Table I.

The face of the questionnaire is shown in Fig. 1. It is seen that two major questions appear on the questionnaire, the first dealing with the positions held during the first five years and the second with the succeeding positions. The graduate was asked to suggest the classification for the several positions held by him. The results were reasonably successful since only a small percentage of all the positions held could not be classified. It will be noted that, in addition to information on employment histories, there were questions relating to post-war employment and college studies. Answers to these questions have been used in the placement of returned veterans and in the formulation of programs for the engineering extension offering of courses.

The results of the survey are given compactly in Tables II to VI inclusive. Table II summarizes data relating to the first positions held by engineering graduates, classified both as to professional field and as to function. The information in the table reflects the

1. Name..... Degree..... in C.E. ☐ M.E. ☐ Metall. ☐ Econ. ☐ E.E. ☐ Min. ☐ Pet. Eng. ☐ Geol. ☐ (Check One) Year.....

2. Transferred to College of Engineering, Berkeley, from.....
After.....years of attendance.

3. Permanent Mailing Address:.....
NUMBER AND STREET; CITY, POSTAL ZONE; STATE

4. Present Occupation:

a. Armed Services: Branch.....; Rank..... Mail Address.....
..... Do you want to make the armed services your postwar career?.....

b. Civilian: Employer..... Date Employed..... Position.....
Do you consider your present position permanent ☐ or temporary ☐.

5. Placement: Do you wish placement assistance? Yes ☐ No ☐. At present: Yes ☐ No ☐. Geographical area preferred:
.....

6. Positions Held During *First Five Years After* College:

	EMPLOYER	PROFESSIONAL FIELD*	POSITION HELD (*Give Exact Title*)	FUNCTION†	DURATION
a.					
b.					
c.					
d.					
e.					

* Professional Field refers to civil, electrical, mechanical, etc., which may differ from curriculum studied. Be as specific as possible as, for example, ceramic, aeronautical, etc.
† Refer to research, design, construction, production, sales, patents, teaching, etc.

7. Principal positions since *First Five Years After* College:

	EMPLOYER	PROFESSIONAL FIELD	POSITION HELD (*Give Exact Title*)	FUNCTION	DURATION
a.					
b.					
c.					
d.					
e.					

8. Study Since B.S. Degree. (Use separate page if necessary). Please list below courses undertaken and institutional auspices.
.....
.....
.....
.....
.....

9. Do you plan further study at the University of California? At Berkeley: Yes ☐ No ☐. At Los Angeles: Yes ☐ No ☐. Are you interested in full-time study ☐ part-time study ☐ evening extension courses ☐ or institutes ☐?

10. What courses would be of most benefit for your particular needs:.....
.....

DATE.....

Return to Room 220 Engineering Building, Berkeley Campus

FIGURE 1

organization of the College of Engineering since the degrees classified as "M. & M." include all degrees in the fields of mining, metallurgy, petroleum engineering and economic geology. From the classification by Professional Fields it will be seen that most of the graduates found their first positions in their major fields. The greatest divergence is found in mechanical engineering and the least in civil engineering.

The classification of positions by functions is relatively difficult due to the lack of sharp lines of demarcation. After some preliminary studies of the questionnaires the following nine groups were defined as indicated:

1. *Apprentice Engineer*—positions whose chief purpose is orientation and to which but little responsibility for production is assigned. A good example is the position of student engineer in any of the large companies which operate training programs. Positions such as draftsman or rodman are also included in this group.
2. *Production, Construction* and *Maintenance*—positions of vari-

TABLE II

CLASSIFICATION OF FIRST POSITIONS

A. Professional Fields—All Positions.

Professional Field of First Position	Degree Received in			
	C.E.	E.E.	M.E.	M. & M.
Civil Engineering	323	15	15	12
Chemical Engineering	2	—	9	3
Electrical Engineering	2	329	16	0
Mechanical Engineering	1	24	311	13
Mining Engineering	—	1	2	76
Metallurgy	—	—	2	18
Petroleum Engineering	2	6	19	79
Economic Geology	—	—	—	14
Non-Engineering	16	34	27	4
Armed Services	18	29	31	15

B. Functional Placement—Engineering Positions Only.

	C.E.	E.E.	M.E.	M. & M.
1. Apprentice Engineer	83(25%)	77(25%)	94(25%)	38(17%)
2. Production, Operation and Construction	74(23%)	99(26%)	71(19%)	87(40%)
3. Testing and Inspection	6(02%)	29(08%)		26(12%)
4. Estimating	22(07%)	16(04%)		30(14%)
5. Teaching	2(06%)	14(04%)	9(02%)	2(01%)
6. Sales	7(02%)	28(07%)	17(05%)	6(03%)
7. Design and Sales	90(27%)	65(17%)	115(31%)	6(03%)
8. Research	15(05%)	41(11%)	62(17%)	21(10%)
9. Administration	5(02%)	3(.8%)	6(02%)	1(.5%)
10. Unclassified	26(08%)	3(.8%)		1(.5%)
	330	375	374	218

ous levels of responsibility and which contribute directly to the manufacturing or erecting operations. Examples are resident engineer, plant engineer, field engineer.

3. *Testing* and *Inspection* positions are exemplified by test engineers on ship trials and by inspectors of finished products.
4. *Estimating* and *Valuation* positions include stream gaging, property appraisals, production cost estimating.
5. *Teaching* positions include both high school and college work.
6. *Sales* positions are those in which the emphasis is apparently more on the fiscal aspect than on the technical aspects of the problem.
7. *Design* positions include technical design, consultation, product development, design and sales engineering in which the predominant characteristic is the fitting of a product to an existing need.
8. *Research* positions exemplified by those in the organizations of large electrical manufacturing concerns such as the General Electric Company.
9. *Administrative* and *Supervisory* positions have to do with the direct operation of a company. Examples are owner-operators of small companies, plant manager, business manager, city manager.

Referring to the second part of Table II certain observations may be made. Between ¼ and ⅙ of all first positions were in the apprentice engineer classification. In the fields of production, testing and inspection and estimating, the M. & M. positions comprised two-thirds of all the positions held by M. & M. graduates, whereas for M.E. graduates the positions in these groups

TABLE III

CLASSIFICATION OF ALL POSITIONS HELD BY FUNCTION

Civil Engineering Graduates

	Years After Graduation			
	0–5	5–10	10–15	15–20
	No. (%)	No. (%)	No. (%)	No. (%)
1. Apprentice Engineer, Surveying, Drafting	112 (18)	9 (02)	1 (17)	0 (0)
2. Construction, Production	114 (19)	64 (17)	28 (16)	15 (17)
3. Testing, Inspection	17 (03)	6 (02)	3 (02)	0 (0)
4. Valuation, Estimating	40 (07)	23 (06)	10 (06)	3 (03)
5. Teaching	6 (01)	7 (02)	3 (02)	2 (02)
6. Sales	11 (02)	6 (02)	5 (03)	4 (03)
7. Design, Design and Construction	166 (27)	119 (32)	54 (31)	21 (24)
8. Research	27 (04)	17 (05)	10 (08)	5 (06)
9. Administration, Supervision	9 (01)	16 (04)	16 (09)	19 (22)
10. Non-Engineering	16 (03)	9 (02)	11 (06)	7 (08)
11. Armed Services	52 (09)	71 (19)	25 (14)	7 (08)
12. Unclassified*	36 (06)	25 (06)	10 (06)	3 (03)

* These positions were specified in the questionnaires as Hydraulics or Sanitary with no specification as to the functional duties involved.

TABLE IV

CLASSIFICATION BY FUNCTION OF ALL POSITIONS HELD

Electrical Engineering Graduates

	Years After Graduation			
	0–5	5–10	10–15	15–20
	No. (%)	No. (%)	No. (%)	No. (%)
1. Apprentice Engineer, Surveying, Drafting	92 (13)	6 (01)	0 (0)	0 (0)
2. Operation, Production, Construction, Maintenance	154 (22)	77 (18)	37 (16)	18 (13)
3. Testing, Inspection	41 (06)	15 (03)	7 (03)	2 (01)
4. Valuation, Estimation	30 (04)	23 (05)	11 (05)	12 (08)
5. Teaching	28 (04)	26 (06)	17 (07)	8 (06)
6. Sales	46 (06)	34 (08)	20 (08)	7 (06)
7. Design, Design and Sales Application, Design and Construction	144 (20)	105 (24)	60 (25)	33 (23)
8. Research Development	61 (09)	35 (08)	17 (07)	12 (08)
9. Administration	6 (.8)	19 (04)	22 (09)	23 (16)
10. Non-Engineering	41 (06)	15 (03)	16 (07)	11 (08)
11. Armed Services	61 (09)	75 (17)	24 (10)	13 (09)
12. Unclassified	8 (.9)	8 (02)	6 (03)	3 (02)

amounted to only one-fifth of the total. The classification of design included more than one-fourth of all M.E. and C.E. positions but much smaller fractions of E.E. and M. & M. positions. Research positions were most numerous in M.E. and least in C.E. The implications of these data, as far as engineering curricula are concerned, seem to emphasize the importance of preparing the graduate for work in production or design immediately after completion of his undergraduate work.

Turning now to Tables III to VI inclusive, it should be noted that the figures given refer to positions rather than to men. Thus the totals in any column would exceed the number of replies if the average man had held more than one position. For example, in the first column of Table III a total of 364 replies gave 606 positions, so that the average man held 1.7 positions in the first five years.

Comparison of the tables shows definite and different trends in the functional occupations of graduates in the several curricula. For example, the construction and design functions for civil engineering graduates continue through the years at a nearly constant value, whereas the administration and supervision function increases slowly but markedly. The same general trends are observed in Table IV for electrical engineers but the corresponding groups in mechanical engineering (Table V) show a definite decrease in the production function. Research furnishes more positions for mechanical engineering graduates than it does for any of the others. The positions of graduates in mining and metallurgy are seen to increase in the valuation and estimating functions and to be almost totally lacking in the design function as the years out of college increase.

This survey has certain implications

TABLE V

CLASSIFICATION BY FUNCTION OF ALL POSITIONS HELD

Mechanical Engineering Graduates

	Years After Graduation			
	0–5	5–10	10–15	15–20
	No. (%)	No. (%)	No. (%)	No. (%)
1. Apprentice Engineer, Drafting, Surveying	108 (15)	4 (3)	0 (0)	0 (0)
2. Production, Construction, Maintenance 3. Testing, Inspection 4. Valuation, Estimation	124 (17)	55 (16)	19 (13)	6 (8)
5. Teaching	24 (3)	14 (4)	7 (5)	4 (5)
6. Sales	45 (6)	34 (10)	12 (8)	4 (5)
7. Design, Design and Sales	197 (27)	118 (35)	43 (29)	20 (27)
8. Research	84 (12)	29 (9)	18 (12)	8 (11)
9. Administration	13 (2)	25 (7)	28 (19)	24 (34)
10. Non-Engineering	32 (4)	14 (4)	9 (6)	5 (7)
11. Armed Services	103 (14)	32 (10)	10 (7)	2 (3)

TABLE VI

CLASSIFICATION BY FUNCTION OF ALL POSITIONS HELD

Mining and Metallurgy Graduates

	Years After Graduation			
	0–5	5–10	10–15	15–20
	No. (%)	No. (%)	No. (%)	No. (%)
1. Apprentice Engineer, Drafting, Surveying	42 (11)	1 (.5)	0 (0)	0 (0)
2. Production, Operation, Construction	143 (38)	76 (34)	24 (24)	12 (17)
3. Sampling, Assaying, Valuation, Testing	43 (11)	8 (04)	4 (04)	4 (06)
4. Geologic Survey, Exploration, Development, Exploitation	46 (12)	39 (18)	23 (23)	16 (23)
5. Sales	10 (03)	10 (05)	7 (07)	5 (07)
6. Design	17 (04)	12 (05)	2 (02)	1 (01)
7. Research	31 (08)	14 (06)	6 (06)	4 (06)
8. Teaching	7 (02)	6 (03)	6 (06)	4 (06)
9. Administration	4 (01)	16 (07)	19 (19)	17 (25)
10. Non-Engineering	4 (01)	8 (04)	6 (06)	4 (06)
11. Armed Services	31 (08)	29 (13)	2 (02)	1 (01)
12. Unclassified	3 (01)	2 (01)	1 (01)	1 (01)

as to the content of curricula and courses. These implications involve not only the subject matter of courses but also the secondary objectives of courses which pertain to skills and techniques useful on first positions. Sweeping conclusions may not be drawn since the data presented are peculiar to the University in that the graduates of this institution locate permanently on the west coast for the most part. The west coast does not present the same oppor-

tunities for industrial employment that would be found in other sections of the country.

Thanks are here rendered to the several persons directly connected with the survey and its summary. Deans L. M. K. Boelter and M. P. O'Brien strongly supported the survey. The questionnaires were prepared and mailed under the direction of Miss Violetta Lane, Administrative Assistant, and summary of data was assembled by Mr. S. N. LeCount, Administrative Assistant.

Electric Training for Industry

A Survey of Electric War Training Programs Conducted by the University of California in Cooperation with the U. S. Office of Education

By CHARLES F. DALZIEL, SAMUEL P. WELLES, and HAROLD A. MOOMAW*

Technical training was largely responsible for the successful transformation of California from a predominantly agricultural economy to a wartime industrial economy chiefly concerned with building and repairing ships and planes. Technical training to meet immediate industrial needs was especially designed and supervised by seven educational institutions within the State under the Engineering Science and Management War Training Program financed by the Federal Government through the U. S. Office of Education. The success with which the assignment was carried out, while impressive, would not justify postwar discussion were it not possible that peacetime emergencies or future wars may present mass educational problems on which E.S.M.W.T. experience may suggest methods of attack.

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Over 200 educational institutions throughout the nation participated in the effort, each offering courses designed to meet special technical training requirements as they developed. The University of California became the largest participant, enrolling over 150,000 men and women in 4,400 courses under direction of Professor Morrough P. O'Brien, Dean of the College of Engineering at Berkeley.

Facilities for conducting classes were organized on a state-wide basis. In addition to using the several campuses and other facilities of the University, emergency war training centers were established in industrial centers and many classes were offered in the training buildings maintained by the training departments of the larger industries. Although courses were offered covering the fields of engineering, science, and management, this paper is limited to electrical war training programs designed to train or upgrade engineers, journeymen electrician, and technicians in the various war industries of the State, with emphasis given to ship production, maintenance, and operation. Experience gained in this emergency training is summarized here in the hope that it may offer practical suggestions

to others confronted with similar problems.

The chief objective of the program was to supply sound training as a basis of attack on personnel shortages and deficiencies in war or essential industries. From the beginning in February, 1941, it was obvious that the desperately needed technically trained workers could not be produced overnight. Three major aims were practical: (1) to bring practicing engineers up to date on new developments; (2) to assist engineers from other fields in changing over to electrical or radio engineering; (3) to upgrade skilled mechanics and technicians.

In general, instruction was offered on three levels:

(1) Courses for skilled mechanics and technicians: These men were not always high school graduates; however, they had completed craft training, had practical experience in their positions, and were potential or current supervisory personnel. Frequently, they were poorly prepared in mathematics and physics so that courses were of necessity descriptive in nature, and the educational program expanded horizontally, that is, successive courses were limited to the same technical level rather than progressing in technical difficulty.

(2) Courses for students having satisfactory backgrounds in mathematics and physics, such as those with junior college training: At this level the sequence of courses expanded vertically, that is, they increased in technical difficulty as do ordinary college courses.

(3) Courses for practicing engineers: Successive courses progressed vertically at a much faster pace than at the two sub-professional levels.

Approximately ten per cent of the 151,202 enrollees in war training classes were in electricity or in courses closely associated with electrical engineering. The total enrollment was of less significance than was the quality of the trainees and their practical opportunity to use the training to advance the war effort. Selection of trainees was made with as much care as the wartime rush would allow, and prerequisites for courses were written to screen out, as far as possible, applicants who were not equipped for the work. Academic prerequisites were used for professional courses presenting subjects normally given as part of an engineering curriculum. For many low-level but badly needed courses, such as those designed to develop supervisors or technical workers, it was necessary to broaden the prerequisites to admit the mature students with practical experience, or else the trainees of greatest potential use to industry would have been eliminated. In general, the minimum prerequisite was high school graduation or equivalent education, or satisfactory completion of a qualifying examination in subject matter basic to the work of the course, and employed or employable in a war industry.

A student was admitted to these war training courses according to an estimate of his probable success made by the E.S.M.W.T. supervisor and based on: (1) an analysis of the applicant's background of education and experience as shown by his application blank, (2) his score on a qualifying examination covering knowledge essential to the course, and (3) a personal interview when the information from the first two sources was inconclusive. No one of these means of rating applications provided accurate measures of likely student success. An industrial training program less rushed for time might well

study, with the help of a testing specialist, both vocational tests and standardized achievement tests as a means of student selection.

Electrical classes generally consisted of 2 to 2½ hours of lecture or 3 hours of laboratory and met once a week for 15 to 20 weeks. Instruction was conducted at various technical levels in electrical theory, design, operation, maintenance and repair, and in the fields of electric power, marine propulsion, communications, and industrial electronics. Public classes were conducted in war training centers in Berkeley, San Francisco, Long Beach, and in various high schools and junior colleges located near vital industries. The public classes were effective in training both engineers and electricians for war industries which lacked sufficient personnel to support individual classes. These classes were usually conducted at higher technical levels than the in-plant classes, many were of strictly graduate level, and advanced courses were given in radio communications, ultra high-frequency phenomena and industrial electronics. Public courses were of necessity more general than in-plant courses, and inevitably included material of secondary interest to some of the class members. As the national organization for war matured, the need for training shifted from preparation for initial employment in war production to training aimed at improving the knowledge and efficiency of employed personnel. The different needs, together with the growing recognition of E.S.M.W.T. by industrial management, fostered in-plant courses as an effective means of providing training in specific requirements for the satisfactory performance of a department or of a group of employees within a given plant. Members of in-plant courses were a homogenous group as far as interests and production experiences were concerned. This established effective learning situations. The instructor, after consultation with management, and an inspection of the plant, knew the make-up of his class, the jobs being done by the students, and their relationship to other jobs in the plant. Thus, it was possible to plan course contents to achieve specific results and to avoid irrelevant material. In-plant classes were held on company time, part time, or after working hours.

Many difficulties were encountered in organizing the program. Industrial contacts already established by various University departments, notably the College of Engineering and University Extension, gave the program an initial point of departure. This was helpful but inadequate in a state so affected by the impact of war. Early consultation with industrial executives vital to national defense indicated little or no recognition of the need for technical training to combat personnel shortages and production problems. From the beginning, a continuous and aggressive plant-by-plant canvass was carried on by E.S.M.W.T. supervisors who were qualified professionally and practically to recognize production problems and training needs, and to recommend possible solutions. Helpful information on local war contracts and manpower needs was secured from Chambers of Commerce, manufacturing associations, engineering societies, war-production councils, the War Manpower Commission, U. S. Employment Service, and other federal agencies. Local "men wanted" ads, state employment statistics, and manpower surveys were studied. Courses in technical subjects related to an industry were offered in the vicinity of the larger plants, and lo-

cal facilities were established in strategic industrial areas in anticipation that technical training would gain acceptance as a means of improving production.

Theoretically, the determination of training needs should be a function of the Training Department of the company concerned. Unfortunately, few such departments in large war plants were close enough to all other divisions in their company to be cognizant of all training needs; furthermore, the training departments in new plants were forced by circumstances to devote most of their attention to training large numbers of employees in a few manual skills. As a result, the needs of rather small groups for specialized training were often overlooked.

The success of the E.S.M.W.T. program depended in a large measure on the type of instructors it was possible to recruit. Experience proved that instructors must possess both practical and theoretical knowledge, be genuinely interested in their subject and students, and like to teach. The pressure of expanding Western industry created competition for the services of engineers and others capable of teaching technical subjects, and made it generally preferable to use part-time rather than full-time instructors. It was recognized early in the program that the supply of professional teachers was totally inadequate, and it was necessary to obtain qualified engineers from various sources. Securing a competent staff, even on a part-time basis, was difficult and at times seemed almost impossible. Manufacturers of equipment being installed on the ships supplied men to teach courses on installation and operation. Power utility engineers discussed problems of electrical maintenance. Plant engineers discussed yard layout, maintenance, and current problems, and officers were obtained from the services to discuss equipment classified as to security.

Acknowledgment and appreciation is due the electrical manufacturers, utility companies, and various branches of the armed forces for allowing their heavily loaded engineers to undertake the additional burden of instruction. Most of the success of the electrical program can be directly attributed to this far-sighted policy of cooperation.

In a program largely dependent upon industrial personnel for a teaching staff, rates of compensation must take into account the instructor's position and salary, his professional or technical education and experience, and the amount of time he is to devote to course preparation, local travel, and classroom teaching. The civilian aspect of the war was fought on a pay basis. Under similar conditions in the future, technical training must meet the going wage which the instructor can earn at his profession in the community, or lower its standards by hiring men who cannot meet industrial requirements.

Aggressive publicity, both in making war industries aware of E.S.M.W.T., and in the promotion of scheduled classes, played a major part in encouraging greater use of E.S.M.W.T. In completing arrangements for in-plant courses, the University supervisor included an offer to supply posters, individual course announcements, house organ stories, and other helpful publicity material, and also emphasized to company executives the importance of seeing that this material was properly distributed and supplemented with promotional aids of their own.

One of the greatest obstacles at the beginning of the program was the indifference, and in some cases hostility,

of management toward University-sponsored training. Many felt that the workers should be forced to learn the "hard way," without the benefit of free education. Some superintendents frankly stated that they wanted their workers kept in ignorance lest they become discontented with their work, or lest they demand higher wages. However, one or two courses were usually sufficient to establish the worth and need for training; subsequent courses received less opposition, and toward the end of the war, training on company time, with Navy or Maritime Commission approval, was exceedingly helpful.

Student response to electrical training has always been good. In fact, in many plants the class attendance was many times original estimates. Industrial workers showed an eagerness to acquire the technical backgrounds to their vocational skills in spite of obstacles such as poor company attitude, transportation, housing, sickness, overtime, and constantly changing work schedules.

The most important factor determining the success of in-plant programs was the attitude of the electrical superintendent. In future programs, one should plan to spend much time and effort in convincing supervisors, personnel, and top management of the value and need for technical training, and the now quite generally recognized fact that technical training does increase production. One should also make every effort to begin large programs as early as possible, for the benefits of training are often long delayed. Too often have we encountered the belated realization that "this training is badly needed, but the course should have been given a year ago to do any good now!" Another source of friction was that a plant would occasionally find its best trained men stolen by a competitor, and would therefore be reluctant to serve as a school for the industry. This circumstance can be overcome only by cooperation between government, labor, and management, and the adoption of an over-all training policy for a given industry.

It is difficult to evaluate an industrial technical training program. Ships are not launched days ahead of schedule because of one electrical class, and although technical instruction is admittedly necessary in the electrical field, any single class may add but little to the reservoir of knowledge available to a particular group. Nevertheless, technical knowledge has been the driving force behind the production miracle recently wrought, and each class contributed its increment. War Training helped to meet the shortage of engineers and skilled technicians, and helped to maintain a group of adequately trained men in the electrical departments. In addition, it effected innumerable savings or innovations, some of which are noteworthy and are mentioned later in this discussion.

The University of California conducted electrical training programs in twenty-one shipyards throughout the State. This included all but the smallest yards or repair bases. Some of the larger yards established electrical training organizations, constructed classrooms, and in one instance equipped a modest electrical laboratory. In most cases, E.S.M.W.T. used classrooms provided by the yard training departments. Some of the smaller yards had no training facilities, and a portable blackboard in one corner of the electric shop, or mold loft sufficed. Many classes were conducted under very unfavorable conditions. Inexperienced

instructors carried on in spite of ever present distractions such as wide variations in attendance due to overtime, men dirty and tired from the day's work, and high noise levels. A spot check at one location indicated that an average of 19½ steam trains passed within a few feet of the class during the two-hour period. Considering such handicaps, the results are indeed surprising.

A careful study indicates high correlation between the intensity of electrical training and the success of the various yards. The correlation is most apparent when one compares the success of E.S.M.W.T. training with the abilities of the yards to change over from simple types of vessels to the complicated succeeding types or to repair work. Lack of space precludes detailed treatment; however, the following examples are of special interest.

Electrical training was started at Moore Dry Dock Company in August, 1942, and twenty-three courses were completed by the early part of 1944. Top management, the Training Department, and the Electrical Department were actively cooperative, and this yard was the first to establish an adequate training program. The yard developed a splendid home-study program for helpers and trainees. E.S.M.W.T. was integrated with the home-study program on higher technical levels for journeymen and above. The increasingly complicated vessels constructed and outfitted in this yard were handled on schedule and additional ships were outfitted here from other yards which lacked trained personnel. Discussions in one class, organized for engineers and foremen, led to design changes which were estimated to have resulted in a saving considerably in excess of a million dollars on a 65-ship contract. In the fall of 1943, this yard cut its personnel ⅓ and was then able to reduce electrical man-hours per ship by about twenty per cent. The management acknowledged that electrical training contributed largely to this outstanding accomplishment. Later an attempt was made to economize by employing a subcontractor. The contractor's men were not properly trained, and the work had to be torn out and done over by the regular workers in the yard.

In contrast, consider one of the shipyards in Southern California. Here an unsuccessful attempt was made to prepare marine electricians for the change from Liberty to Victory ships in January, 1944. Only when difficulties became unsurmountable was E.S.M.W.T. given a real chance. A concentrated program consisting of three 2-hour meetings per week on company time was inaugurated—but this was too late to prevent serious delay in the outfitting of the first ships in a series of vitally needed naval vessels. As a result the yard failed to meet production schedules. Four hulls were towed 500 miles to the San Francisco area, and five were towed 1,000 miles to Vancouver, Washington, for outfitting where trained personnel were available. This waste of priceless time, not to mention money, could have been avoided by proper and timely training.

The most comprehensive technical program was organized for Bethlehem Steel Company, Ship Building Division, Terminal Island. The first step was a review of existing craft training and further training needs by a plant committee made up of the Assistant Manager, the Sales Manager, Management's Representative, the Superintendent of Hull Repairs, and the Superintendent of Machinery Repairs. Care-

ful plans for instruction and for selection of trainees were worked out with the help of the E.S.M.W.T. supervisor, resulting in a program which included Marine Electrical Equipment, Marine Piping, Marine Diesel Engines, Steam Turbines, Steam Boilers and Auxiliaries. The Assistant Manager reviewed each qualifying examination and disqualified those who, in his opinion, would benefit least from instruction. As the program progressed, permission to take successive courses depended upon achievement in the preceding course. The students were limited to qualified men in the repair and new construction departments plus a specified number of employees from associated departments, such as drafting, testing, and purchasing. This was done so that representatives of the associated departments would be familiar with technical problems affecting their work. The instructors were selected by E.S.M.W.T., and individually interviewed and approved by the Assistant Manager. This program began in March, 1944, and was conducted on company time.

Classes for electrical workers at the Richmond shipyards were offered continuously from October, 1942, until the termination of the program, June, 1945. A special course for electrical test engineers at one yard resulted in reducing the testing time from six to three days, and this yard was called upon by neighboring yards for testing assistance. In another yard, the Maintenance and Marine Departments were managed under one superintendent. Classes for maintenance electricians were started in October, 1942, and were continued until July, 1944. In January, 1944, an intensive program on company time was started to prepare marine electricians for the change from Liberty to Victory ships. As a result, the yard completed its ships on schedule without outside help. In contrast, a third yard was organized with separate Marine and Maintenance Departments. The superintendent of the Marine Department was not interested in training until the yard changed from Liberty to Victory ships in the spring of 1944. A few classes were organized, but they were too late to affect production. As a result, this yard required outside assistance in outfitting and testing its ships. The Maintenance Department was strongly in favor of training and conducted its own Craft Training Program. This was coordinated with the E.S.M.W.T. at the journeyman level with very satisfactory results. In a fourth yard, an attempt was made to start a class in May, 1943, but failed because of the lack of cooperation from supervisory electricians. When the yard turned to more complicated types of vessels in the spring of 1944, we received a frantic call for assistance, and three classes were set up at once. All three failed at the second meeting because at that time a subcontractor was called in to do the electrical work on the ships due to the lack of adequately trained personnel.

Another kind of failure might be mentioned. The electrical superintendent of a small repair yard heard about the training programs and became so enthusiastic that he developed a classroom at one end of the electric shop. A class was started with an enrollment of about 60 and with high esprit de corps. Unfortunately, the effort soon failed due to poor choice of an instructor, and all efforts to make amends were without success.

Marinship Corporation did well with the earlier, simpler types of ships, but when it began to build electric-drive

ships in January, 1943, the greater complexity of the electric installations brought out the need for technical training. Two classes were organized in turbo-electric propulsion equipment; these met twice a week in order to make the training effective for the construction of the first ship. These classes were held both in the company training school in Sausalito and in the War Training Center in San Francisco. Subsequent classes in electrical maintenance were continued until September, 1944. This yard completed its contracts on schedule, and much of this success is attributed to E.S.M.W.T.

At the beginning of the program, Washington officials were of the opinion that E.S.M.W.T. would be of no value to military or naval establishments, and the majority of the training officers assigned to the naval yards or drydocks in California were in agreement with this policy. However, many of the local civilian electrical superintendents felt quite differently, and eventually programs were established at Terminal Island, Hunter's Point, and Mare Island. Approximately 600 were enrolled in electrical classes at Hunter's Point and Mare Island when notice of termination of E.S.M.W.T. was received.

Cooperative instruction with the services was another significant part of the program. The turbo-electric tankers and turbo-gear Victory ships developed in 1943 and 1944 were designed to operate at higher temperatures and pressures than marine engineers were accustomed to handling. Furthermore, the inclusion of electric drive and electric auxiliaries proved to be formidable innovations. In order to prepare engineers to operate these ships, the United States Maritime Service established a school at Sausalito. Licensed marine engineers attended this school for three weeks, during which time they were transferred to the payrolls of the United States Maritime Service. Day classes were conducted by U.S.M.S. officers and much time was spent in the partially completed hulls, studying prints and piping layouts, trial runs, etc. Technical lectures were given under E.S.M.W.T. by engineers who were obtained from the manufacturers supplying the steam and electrical equipment being installed in the ships. This cooperation of E.S.M.W.T. and U.S.M.S. brought the latest and best technical information to the students and gave them a satisfactory combination of theory and practice. A second Maritime Service school was established at Richmond, and a third on the East Coast. Although this third school was organized with the assistance of a former University of California E.S.M.

CRAFT TRAINING
TRAINEE 3RD CLASS
ORIENTATION NEW EMPLOYEE, SAFETY, MATERIAL, TOOLS AND EQUIPMENT, ELEMENTARY WIRING, POWER LAYOUT OF YARD
VOCATIONAL INSTRUCTOR
4 HRS. PER WEEK- 10 WEEKS
TRAINEE 2ND CLASS
WIRE AND CABLE, TYPES, SPLICES AND CONNECTIONS, COLOR CODES, ELEMENTARY CIRCUITS
VOCATIONAL INSTRUCTOR
4 HRS. PER WEEK- 10 WEEKS
TRAINEE 1ST CLASS
FUSES, SWITCHES AND CIRCUITS, TRANSFORMERS, MAINTENANCE OF EQUIPMENT, MOTORS, PANELS, ETC.
VOCATIONAL INSTRUCTOR
4 HRS. PER WEEK- 10 WEEKS

FIG. 1. Suggested educational program for shipyard trainee electricians for large and small organizations.

W.T. supervisor, and an officer from the U.S.M.S. school at Richmond, subsequent supervision was handled by an Eastern university. The Sausalito and Richmond schools were later lengthened to a four-week term, and the two schools were subsequently moved to the U. S. Maritime Officers School, Alameda. A total of 1,248 marine engineers attended these two schools during the period September 20, 1943, to June 30, 1945. This combination of training with the E.S.M.W.T. and the U.S.M.S. was considered so valuable that when E.S.M.W.T. was terminated, the War Shipping Administration contracted with Engineering Extension to continue the instruction until July, 1946.

Similar cooperative instruction was provided for United States Navy officers about to be assigned to engineering positions on combat vessels at the Operational Training School, Treasure Island, and at the Naval Training Center, Terminal Island. The E.S.M.W.T. lectures were given at unusual hours, the result of compromise often necessary when employing practicing engineers as part-time instructors. A total of 347 officers were enrolled in these classes before changes in the Pacific theater led to their termination.

Efficient training of large groups of workers, especially those employed in smaller industries, was achieved through cooperation with locals of the International Brotherhood of Electrical Workers. The psychological reaction of students was often better than in-plant courses. In these union classes, as in the public classes, there was no incentive to take training in order to achieve advancement in an organization simply by having attended a course of instruction.

In addition to the formal instruction, each class served as a clearing-house for problems arising daily in the war industries in which the students were employed. In-plant classes obviously could stress particular troubles in a particular plant, yet the public and union-sponsored courses had their share of special benefits. For example, conclusions reached in one public course

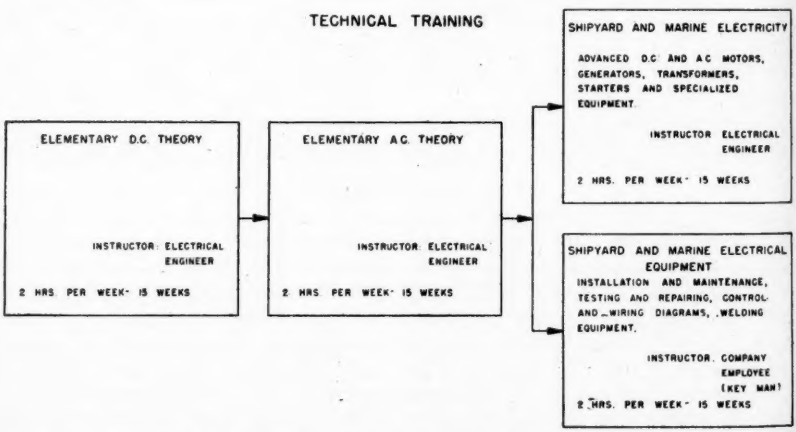
TECHNICAL TRAINING
ELEMENTARY D.C. THEORY
INSTRUCTOR: ELECTRICAL ENGINEER
2 HRS. PER WEEK - 15 WEEKS
ELEMENTARY A.C. THEORY
INSTRUCTOR: ELECTRICAL ENGINEER
2 HRS. PER WEEK - 15 WEEKS
SHIPYARD AND MARINE ELECTRICITY
ADVANCED D.C. AND A.C. MOTORS, GENERATORS, TRANSFORMERS, STARTERS AND SPECIALIZED EQUIPMENT
INSTRUCTOR: ELECTRICAL ENGINEER
2 HRS. PER WEEK - 15 WEEKS
SHIPYARD AND MARINE ELECTRICAL EQUIPMENT
INSTALLATION AND MAINTENANCE, TESTING AND REPAIRING, CONTROL AND WIRING DIAGRAMS, WELDING EQUIPMENT.
INSTRUCTOR: COMPANY EMPLOYEE (KEY MAN)
2 HRS. PER WEEK - 15 WEEKS

FIG. 2. Suggested educational program for shipyard journeymen electricians for small organizations.

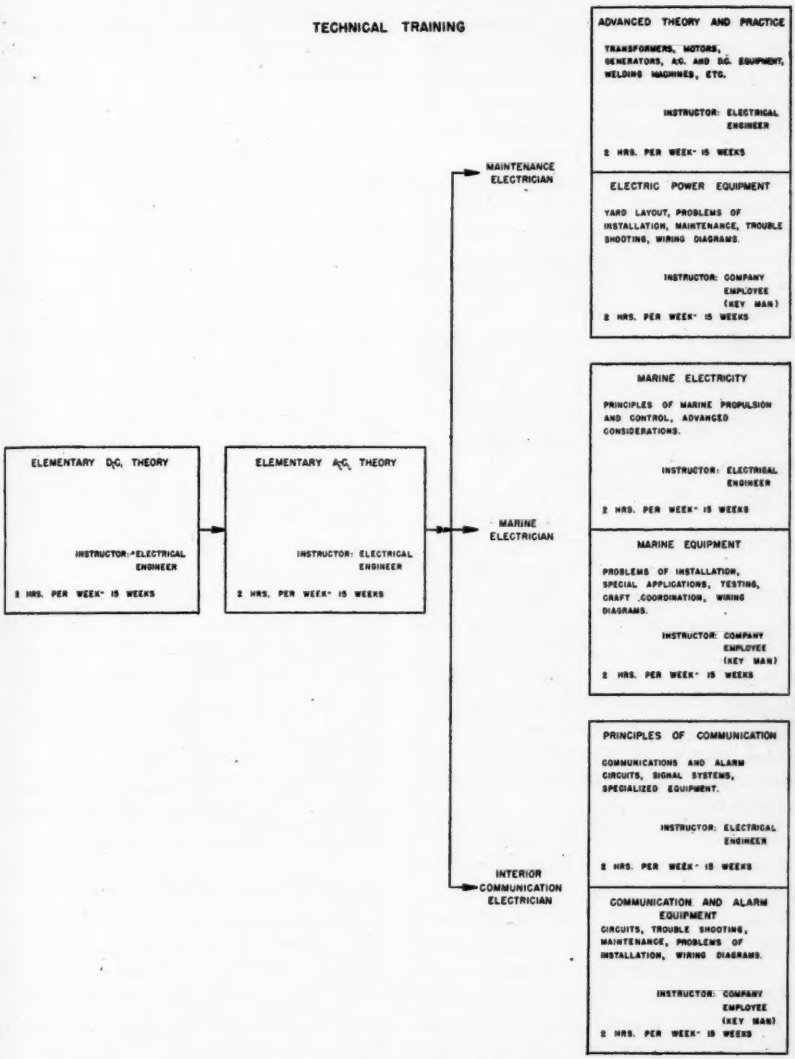
TECHNICAL TRAINING
ELEMENTARY D.C. THEORY
INSTRUCTOR: ELECTRICAL ENGINEER
2 HRS. PER WEEK - 15 WEEKS
ELEMENTARY A.C. THEORY
INSTRUCTOR: ELECTRICAL ENGINEER
2 HRS. PER WEEK - 15 WEEKS
MAINTENANCE ELECTRICIAN
MARINE ELECTRICIAN
INTERIOR COMMUNICATION ELECTRICIAN
ADVANCED THEORY AND PRACTICE
TRANSFORMERS, MOTORS, GENERATORS, A.C. AND D.C. EQUIPMENT, WELDING MACHINES, ETC.
INSTRUCTOR: ELECTRICAL ENGINEER
2 HRS. PER WEEK - 15 WEEKS
ELECTRIC POWER EQUIPMENT
YARD LAYOUT, PROBLEMS OF INSTALLATION, MAINTENANCE, TROUBLE SHOOTING, WIRING DIAGRAMS.
INSTRUCTOR: COMPANY EMPLOYEE (KEY MAN)
2 HRS. PER WEEK - 15 WEEKS
MARINE ELECTRICITY
PRINCIPLES OF MARINE PROPULSION AND CONTROL, ADVANCED CONSIDERATIONS.
INSTRUCTOR: ELECTRICAL ENGINEER
2 HRS. PER WEEK - 15 WEEKS
MARINE EQUIPMENT
PROBLEMS OF INSTALLATION, SPECIAL APPLICATIONS, TESTING, CRAFT COORDINATION, WIRING DIAGRAMS.
INSTRUCTOR: COMPANY EMPLOYEE (KEY MAN)
2 HRS. PER WEEK - 15 WEEKS
PRINCIPLES OF COMMUNICATION
COMMUNICATIONS AND ALARM CIRCUITS, SIGNAL SYSTEMS, SPECIALIZED EQUIPMENT.
INSTRUCTOR: ELECTRICAL ENGINEER
2 HRS. PER WEEK - 15 WEEKS
COMMUNICATION AND ALARM EQUIPMENT
CIRCUITS, TROUBLE SHOOTING, MAINTENANCE, PROBLEMS OF INSTALLATION, WIRING DIAGRAMS.
INSTRUCTOR: COMPANY EMPLOYEE (KEY MAN)
2 HRS. PER WEEK - 15 WEEKS

FIG. 3. Suggested educational program for shipyard journeymen electricians for large organizations.

made it possible for a Bay Area engineer to fly to Southern California and activate the electronic equipment on a group of B-17's which had long been grounded. Discussions in one union-sponsored course led to the correction

of resonant currents and resultant frequent faulting in a large transformer serving an arc furnace which supplied castings for two large Navy yards, and every failure required a shut-down of at least two weeks for repairs.

During the early months of War Training, particularly in the Richmond area, much time and energy was lost because of the lack of cooperation and even hostility between War Production Training and E.S.M.W.T. The former was set up on a "vocational" level, yet its upper limits were not defined. As a result, there was much conflict over electrical courses at the lower levels. A clear-cut separation should be made at the journeyman level. This separation was effected in the program as it developed, but a consecutive, integrated training pattern never evolved. As a result of consultations with electrical superintendents, training directors, and instructors, training programs were worked out to effectively coordinate vocational and technical training for both large and small organizations. Although the outlines shown in Fig. 2, and 3 were never achieved in their entirety, they are included for future reference.

No University credit was given for E.S.M.W.T. courses, but students successfully completing them were given Certificates of Completion. Although certificates were given for satisfactory completion of both public and in plant courses, an effort was made to encourage the student to complete substantial work in the field, and rather elaborate certificates were awarded upon successful completion of 125 class hours of instruction. This usually represented completion of four courses and required approximately one 2-hour meeting per week for a year.

The success of the electrical program was largely due to the man-hours spent in talking with workers and students, selecting capable instructors, and actively supervising the organization and conduct of each course. This resulted in a relatively high cost per student hour, but was well repaid in efficiency of instruction and in respect and esteem for the program. Many California executives have taken the time and effort to write letters of appreciation to the University, expressing the opinion that E.S.M.W.T. made a material contribution to the war effort.*

* "Training for War Industries," mimeographed edition, September 30, 1945, University of California.

Undergraduate Preparation for Graduate Study . . . Through Applied Mathematics*

By J. L. SYNGE

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Anyone who would make reliable statements about what actually goes on in the many engineering schools of this country would need to be a man of vast experience. I am comparatively ignorant. So I generalize from the small evidence I have and speak subject to correction.

I have the impression that the educational pattern is remarkably uniform. Frankly, this surprises me, and I can only attribute it to a timidity which seeks to avoid criticism by following an established pattern. I am certainly not competent to say whether the common pattern in engineering education is good or bad. I can speak only of my specific interests and judge them from my own point of view.

To avoid wandering into generalities, permit me to cite an example:

For several years I taught theoretical mechanics to a small group of picked engineering students. I could meet them only one hour a week because their time was taken up with other much more important subjects. These students were in their third year and had had training in mathematics far beyond the usual. They had also had extensive courses in physics, as well as the customary engineering courses. So, when I took on the course, I did so with some nervousness that there might be nothing left to teach them. To break the ice, I started talking about the simple pendulum as something that we were well acquainted with. To my amazement I found that not one of the class could derive the differential equation of motion. It appeared that never before had they been asked to take a piece of apparatus and coolly and confidently translate the physical problem connected with it into mathematical language. If I gave them the differential equation, they could solve it. If I asked them for the periodic time, they knew what it was. But the essential link was omitted—the link (I may say without exaggeration) on which modern engineering advancement depends to a large extent. Once I came to understand what they did know, and once they came to see that tidiness of thought may be as important as tidiness in drawing, we got on famously, and I hope that they enjoyed the work as much as I did.

I have the impression that such an experience is by no means unique and that it reflects a common defect in engineering education, if it is a defect. Perhaps it is not important for engi-

* Presented at conference of the Division of Graduate Study, S.P.E.E., St. Louis, June 20, 1946.

neers to be able to construct the differential equations which control a problem in which they are interested. Probably for a great many practising engineers it is something that they never do. But do these same engineers find use for the calculus? I expect not. In short, we might as well admit that there are many engineering students to whom mathematics was, is, and will be something to which they are exposed, and which acquires no significance for them professionally. They are the slide-rule men, and I intend no disrespect towards them.

But we are talking tonight about the type of student who is qualified by interest and natural intelligence to go on to graduate work. That graduate work may be experimental in character, or it may be on the theoretical side. If it is experimental, the graduate student may be able to carry out effective research with very little mathematics; it is, however, becoming increasingly hard. The student may not need to work creatively in mathematics, but he is almost certain to encounter papers written in mathematical form, which he will have to evaluate. The graduate student working on the theoretical side will find mathematics essential.

It appears evident, therefore, that the student intending to proceed to graduate work in engineering should be well equipped mathematically. What does that mean? What is a mathematician anyway? That is a difficult question to answer. Suppose, without mentioning names, we think of the leading mathematicians in the country, and ask: Do we want graduate students in engineering to be like those men, on a small scale? The answer is: Yes and No. We want the engineers to resemble the mathematicians in their clarity of thought and their appreciation of the power and limitation of mathematics. But we do not require the engineer to be competent in the techniques of modern mathematics. To be sure, there would be no harm to have that competence, but there are more important things, as I shall try to point out.

Let us put first things first. The engineering graduate student has before him a certain problem—a problem involving perhaps a stress distribution, or determination of vibrations in a structure, or a problem in electromagnetic radiation. He considers how to attack the problem. Perhaps an experimental method is best. But undoubtedly he must not rush blindly into an experimental technique. Perhaps the problem admits a mathematical solution, which will be more general and less costly than the experimental solution. How is he to find out whether such a mathematical solution is feasible? There appears to be only one way, and that is to have a deep acquaintance with, and power over, mathematical methods as applied to the type of problem encountered in engineering. Therefore, if we are to prepare engineering students for graduate work, we must make sure that they have this knowledge and power.

I am a scientist, not an engineer, and it may be presumptuous for me to set down a scale of values in engineering research. Nevertheless, here it is.

First, I put the *answer* to the problem. It doesn't matter whether you dreamed it, or saw it written in the clouds, if you have got the right answer you have delivered the goods (Reference to Oliver Heaviside and Sir Charles Parsons).

Secondly, I put a convincing *justification* of the answer. If an answer

can be tested experimentally, well and good. But experimental tests are necessarily particular, and a mathematical argument based on well-accepted foundations will carry wider conviction.

Third, I put *understanding* of the method. This implies a sense of power which permits the discoverer to apply the same or a similar method to other problems.

Let us repeat, then, the three in order of value: first, the answer itself; second, its justification; and third, understanding of the method.

If it were possible to get answers to problems systematically by superhuman revelation, every engineering school should have a course in superhuman revelation. But we don't think that practical. So, while we admit that the answer is the most important thing, we do not say to a student: "Here is a difficult problem. You have no idea how to tackle it. But come back tomorrow with the answer."

Since there can be no justification of an answer until the answer is found, we must pass over that, and come to the *understanding of methods*. And here we plunge right into education, for what is education in engineering science but the teaching of the understanding of methods?

How are we to teach students to understand mathematical methods which will be useful to them in graduate work? This understanding takes time. I am wholly opposed to deferring until after graduation an inculcation into such methods. The methodology or technique should, as a matter of fact, start away back in high school, but let us omit pipe dreams of that sort. In the domain over which we have control, however, we can within limits do what seems best.

What I have to say would sound very platitudinous in London or Paris, or a normal Berlin or Rome. If it were announced that someone would speak on the place of applied mathematics in the undergraduate preparation for graduate study in engineering, the potential audience would simply say "But of course," and adjourn to the nearest bar. It is a peculiarity of American engineering education that it should be necessary to say what appears obvious. And it appears necessary not only to say it, but to shout it, which is an unpleasant thing to have to do.

But the cold facts are these. By some strange turn of fate, modern civilization began round the year 1600 (you can choose your date). Instead of leaving difficult ideas to rest in peace, men chose to grapple with them. They evolved two essential methods of attack on scientific problems—the experimental and the mathematical, which were supplementary, not antagonistic. In the mathematical attack, concepts like time, velocity, acceleration, mass, momentum, and force had to be clarified and given precise meanings. It was not easy. Even Newton himself failed to be completely clear on the definition of time.

It became convenient to classify mathematics into pure mathematics and applied mathematics. But as long as the subjects remained relatively small, it was possible for a man to work extensively in both, and it was only about a century ago that a definite cleavage began. Now the cleavage is great, and at present engineering students are for the most part taught their mathematics by men who have no interest in applied mathematics, and do not even know its vocabulary. That is no reflection on the competency of

these teachers. If an engineering student learns German, he does not expect his German teacher to teach more than German. Similarly, there would be less misunderstanding if it were recognized that teachers of mathematics teach pure mathematics, and any applications they introduced in their teaching are a bonus. And, in my opinion, it is a useless bonus, as I shall try to explain.

The main fields of applied mathematics are mechanics, hydrodynamics, elasticity, electromagnetism, thermodynamics, and heat conduction. There is of course also statistics, but I feel that statistics is already coming into its own, so I omit it from the present discussion.

Each of these subjects has its vocabulary, its axioms, its chain of reasoning—in fact, its structure. No one can possibly learn mechanics by exercises in a calculus class. It stands on its own feet as a difficult and beautiful subject. In fact there is only one way of learning mechanics—namely, by learning mechanics.

Engineering students do learn mechanics. In a few places they are taught by mathematicians—more frequently by physicists or by engineers. Is anything wrong with this? Surely not, if the men who teach it teach it well. But we cannot fail to notice a curious discontinuity. Pure mathematics is taught by men who are in the direct line of descent from the men who created pure mathematics—some of the teachers are actually creating pure mathematics here and now. But the bases of applied mathematics were laid by men who were steeped in mathematics—Newton, Euler, Lagrange, Hamilton, Gibbs, Maxwell—and so it would seem more natural if the subject in these days were in charge of their linear descendants. That means, in effect, that not everyone is competent to teach applied mathematics. He may carry the label mathematician, physicist, or engineer—the essential thing is that he should be an applied mathematician.

The important question relative to the subject of our discussion tonight is this: In the engineering schools of the country, what facilities are there for an undergraduate of talent to receive an adequate initiation into applied mathematics, in order that he may be able to do creative research work in that field as an enginering graduate student? If the answer is that the facilities are good, then we may be well satisfied. If the facilities are not good, it is time that something be done about it, for it is a question of national importance in the present troubled state of the world.

I have a word to add in interpretation. Since applied mathematics has been so largely abandoned as a field of research by professional mathematicians, the subject will degenerate into trivialities and obscurities unless some group undertakes to handle it on a high scientific plane. I mean that applied mathematicians must not be tied to calculating machines. They must have the power of generality shown by pure mathematicians. Where are such men to be found, and how are they to be supported? The two questions hang together. As soon as adequate means of support are obvious, the talent will come up, because the scientific history of the past three hundred years shows that applied mathematics touches deep motivations, partly curious, partly aesthetic, and partly constructive in the engineering sense.

I have little hope that either mathematicians or physicists will pursue this

idea with any enthusiasm. Will engineering schools accept the view that applied mathematics is a high-priority subject? If they will do so, and do so with some resolution, then, if a meeting is called again in 20 years to discuss this same topic, I shall move that a paper like this be taken as read, and that the meeting adjourn to the nearest bar.

Before I sit down I have just one more thought to put forward. We all know what an electrical engineer is, or a mechanical engineer. Either carries a professional status, which is both a dignity and a responsibility. He is expected to make decisions in the field of his competency. But in the higher mathematics of his profession, the electrical or mechanical engineer is an amateur. This I say in general terms, because exceptions are obvious. But I do mean that a competent electrical or mechanical engineer can, without violating his professional status, declare that this or that piece of mathematical reasoning is too much for him. I believe that this is inevitable, on account of the present scope of each of the branches of engineering. And what I propose in all earnestness is the establishment of professional status for the mathematical engineer.

In the medical profession there are specialists for this and that part of the body—eye, ear, nose, throat and so on—but there are also specialists who cut across the geographic lines so to speak, blood specialists, for example. My idea of the mathematical engineer is like that. He would have considerable knowledge of one or more branches of engineering, but his specialty would be applied mathematics. In that field he would claim competence, and would act as consultant for engineers in the several established branches. This is a serious question, touching national security. We have lots of pure mathematicians and lots of engineers, but very few mathematical engineers. Unless a definite and attractive goal is set up to beckon young men, they will follow the present beaten paths which lead to many places, but very rarely to competence in applied mathematics.

Teaching Mathematics to Engineers*

By L. E. GRINTER

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If I were teaching mathematics to engineers, I would do it just a little differently than most mathematics teachers whom I have known. But before we go into that little difference that I believe might make a great difference in results, let me be specific about the fact that I do not consider engineering teachers qualified to teach mathematics. When we have a toothache, we go to a dentist; and as engineers each of us has his own specialty. Teaching mathematics is the specialty of the mathematician. It is hardly modest for us to offer to show him how to perform in the field of his specialty. But when the mathematician starts to teach mathematics to engineers, he becomes not only a mathematician but a practitioner of educational psychology as well. In this field of psychological reactions in which both mathematicians and engineers are amateurs, the engineering teacher may be able to pass on a few useful suggestions to the mathematician.

Perhaps I should stop here to clarify my disagreement with those who feel that training in mathematics would be improved by hiring engineers as mathematics teachers. The field of mathematics, when rigorously studied, develops valuable characteristics in the student. There is a mental discipline produced through the rigorous study of pure mathematics which is necessary to basic engineering thinking, but which I believe engineers would neglect. This discipline depending upon the rigorous procedures of the mathematician (which the engineer is forced to slight if he is to achieve practical results in limited time) is associated with such practices as care in stating premises, conditions of sufficiency clearly defined, and similar matters. For example, engineers would pass up the rigorous thought that should be given to the subject of the differential to reach the practical study of slopes.

The education that the mathematician receives during his study for the doctorate is of course far more extensive than he can impart to an engineering student in two years of contact, but no shorter period of indoctrination in the rigorous thinking of mathematics will produce a real mathematician. This is merely a parallel to our insistence that engineering teachers know far more about their respective fields of engineering than they are expected to transmit to their students. There is a certain quality of thought that sophomores could not be expected to transmit to freshmen or graduate students to undergraduates. Only one who knows all or at least most of the ramifications of a subject can teach it prop-

* Presented at the Conference on Mathematics, S.P.E.E. meeting, St. Louis, June 20–23, 1946.

erly. No engineer who is not a fully trained mathematician could be expected to maintain a standard of instruction in the field of mathematics that would indoctrinate the students adequately in basic principles.

I have taken some space to explain this point of view because I continue to hear complaints from engineering teachers and teaching departments that we should ourselves take over more and more of the teaching function in mathematics so that our engineering students may be more able to apply mathematics to engineering problems. There is a mistaken concept, it seems to me, as to what the division of duties between the engineer and the mathematician should ideally be. Perhaps this could be made clearer by studying the way mathematics is and always must be applied to the solution of an engineering problem.

Before an equation can even be written, we must face the problem of expressing the physical situation in mathematical terms. Then relationships must be established that result in equations which we can proceed to try to solve. When we criticize students for their failures to solve engineering problems by mathematical tools, we commonly assume that the students are inadequately trained in mathematics. Actually, the failure is almost always in setting up the proper equations, not in solving them. The student finds difficulty here because neither his mathematics courses nor his engineering courses have given much attention to the very important technique of expressing an engineering problem in terms of mathematical relationships. Probably the engineering student received more training of this nature in his sophomore course in physics than in all of his courses thereafter.

It is thoughtless of us to attack the teaching of mathematics exclusively for this almost universal weakness. The mathematician's contact with the engineering student is mainly in the freshman and the sophomore years. At that level, neither the student nor the mathematics teacher can be expected to know much about engineering. Such fields as thermodynamics, fluid flow, aerodynamics, heat transfer, internal stresses, and vibrations are yet to be studied. They cannot be used as examples even if the teacher of mathematics could be encouraged to interest himself in such applications. The fact is that the mathematician has a grave responsibility in teaching students how to solve equations. If we consider that to be his entire responsibility, we will have to conclude that he has discharged it reasonably well. It is not surprising that he has avoided the problem of how his mathematics is used in a dozen engineering specialties. No engineer successfully works in more than two or three of these fields, while most engineers confine themselves to one.

To me, it seems clear that if we want our students to be able to express physical problems in mathematical terms we must undertake to teach this as a basic analytical technique. When the matter only comes up spontaneously in certain of the more theoretical courses, the student considers the process to be a part of that particular subject matter without recognizing the universal application involved. For example, flow of water, flow of steam, flow of air, flow of electricity, and flow of heat are usually treated in separate courses under different instructors. Clearly in some place we should study the techniques of expressing physical problems of flow in mathematical terms. Clearly, too, all engineers who are of a rather

scientific bent might as well study the basic mathematical approach to the subject of flow together in one class. Many systems of teaching may be devised to accomplish this objective. The system is not important, but the objective must be achieved if we are to produce a better quality of engineering research men, scientific designers, development engineers, and engineering teachers for the coming decade.

But I do not want my defense of the mathematician to be taken as an indication that I think he has been as successful as he could hope to become. In the beginning, I said that if I were teaching mathematics I would do it a little differently than most mathematicians whom I have known. That little difference would have virtually nothing to do with the subject matter covered, which is largely fixed by necessity, nor with the emphasis placed upon mathematical rigor, which I consider valuable. The difference would be only in the kind of salesmanship used in the classroom. Every teacher is a salesman of his subject and, fortunately, most teachers recognize this important fact. The weakness of mathematicians in their instruction of engineers lies in the fact that they present their courses and direct their salesmanship toward the concept that mathematics should be studied for its own sake rather than because it is the most powerful tool in the engineering field.

If I were a mathematician, I would recognize the fact that my subject was a useful tool, in fact the most powerful of all scientific tools, and I would never let the engineering student forget that fact for a single moment. I would not expect ever to be able to discuss intelligently problems in all fields of engineering science, but I would dig up enough simple applied problems to scatter through my course so that the student could never miss their significance. Then I would learn in general rather than specific terms where each bit of mathematics found an application in science or engineering and I would never fail to point out that "today we are studying a mathematical equation used in analyzing the flow of heat between concentric cylinders" or whatever application might be involved. To learn the general uses of mathematics does not require study so much as social conversation during which both the engineer and the mathematician would find new interests.

I haven't too much hope that the mathematician and the engineer will get together and produce a very great revolution in the teaching of mathematics. But an evolutionary process has been going on and will continue for many years ahead. Until the beginning of World War II, the number of mathematicians employed by industry was very small indeed. Industry had not tried subdividing the job of solving technical problems by letting one person or group set up the equations and by providing expert mathematicians to solve them. The pressures of war forced this experiment and it worked surprisingly well—so well that industry will keep many of its wartime mathematicians and no doubt will hire more.

We may soon find that we have a reasonable percentage of our mathematics teachers who have worked with engineers on industrial or government research projects. As soon as this influence is felt, we may expect a gradually increasing emphasis upon the importance of mathematics as a tool subject with improved student interest and attention. This situation is no different than our own unwillingness to

retain graduate students in engineering as permanent teachers until they have acquired some experience with engineering practice. The teacher of mathematics who studied mathematics because he enjoyed it and who has never used it as a tool for the solution of physical problems may some day find that he is in competition for student interest and attention with the mathematician having some industrial experience. When that situation develops, we are sure to find more attempts to bring into the classroom the concept of the great usefulness of mathematics as a scientific tool. I believe that this little difference in the way that the subject is presented might produce a great difference in the success achieved in teaching mathematics to engineers.

Alternative Methods of Velocity Determination in Mechanisms*

By I. W. SMITH

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Nomenclature

Points in mechanisms are designated by capital letters A, B, C, D, etc.

Links are designated with lower case letters, a, b, c, d, etc. In all illustrations, "d" is the *fixed* link.

ω is angular speed in radians per second. A lower case subscript designates the angular speed of a definite link.

V is linear velocity in feet per second. A capital letter subscript indicates absolute velocity of the point represented by that letter. Two subscripts represent relative velocity thus: V_{CB} is the velocity of C with respect to B.

Lengths are represented in the case of links by the lower case letter of the link, and for vectors or distances by the terminal points and an overbar. Thus the length of the line between points 2 and 5 is $\overline{2\text{–}5}$.

It is a characteristic of engineers to continually strive for better products with greater economies in time and money. This is no less true of those engaged in engineering instruction and results in a continuous process of evaluation and revision in teaching methods and courses. Criticism by men in industry, criticism by the students themselves, experience gained in special projects such as the war-time accelerated courses, etc., all contribute toward a better engineering education. However, the most important factor in this progression is a free interchange of experiences and ideas among those who are closest to the problem.

Many books on mechanism have been published in which methods of velocity determination are covered to a greater or lesser extent. It is hoped that the outline of methods given in this paper will serve as a basis for discussion of their relative merits and the extent to which they can and should be covered in the kinematics courses of engineering colleges.

It is unlikely that a single answer to the question will satisfy everyone, since the amount of time available for covering the subject is variable and each educator has his own ideas on what portions of the work should be stressed. However, it may be possible to outline a reasonably uniform policy that will give maximum satisfaction to the requirements of industry and that will, at the same time, be practicable from a teaching standpoint.

One difficulty involves a decision as to what extent the course should be broad enough to adapt the student to a variety of problems and yet be sufficiently narrow to make him of

* Presented at the Machine Design Session of the Mechanical Engineering Division, S.P.E.E., St. Louis, June 20–23, 1946.

immediate use to industry. A criticism frequently made by industrialists points out the necessity of further training before a young graduate can handle specific problems. It is inferred from this that the college has failed in its purpose, and that the content of the courses (and perhaps the personnel of the staff) should be changed accordingly. Of course the validity of such criticism would be recognized if there were only a few of these special problems. Actually, however, there is such great variety that it becomes increasingly necessary to teach a few methods of the most general application and leave the particular solutions to the organization immediately concerned. Here, then, is the first criterion in the selection of a method for determining velocity; it should be of general rather than specialized importance.

The second consideration is concerned with the student's ability to absorb and understand the principles placed before him. The relative complexity of a method would be of little importance if a student was expected merely to memorize it and then use it as memorized. To encourage *thinking* on the part of the student and to provide him with methods that he can adapt to any set of conditions, requires that the information be within his mental grasp and commensurate with his abilities and previous training. This is not to say, of course, that the more complex methods are undesirable or even that they should not be included in a textbook, but merely that they are better left to post-graduate training when the need for them has been more definitely expressed.

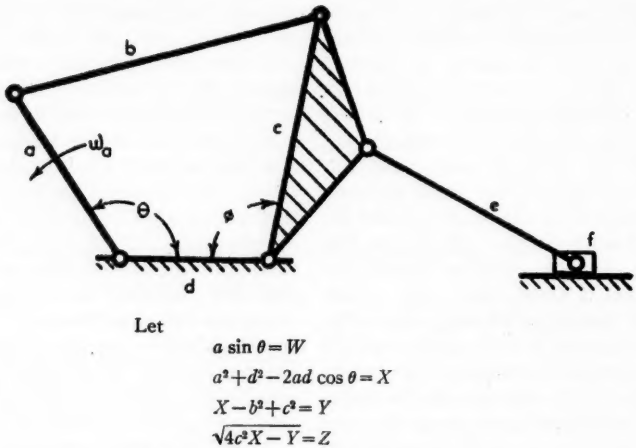
In the majority of machines there is uniform motion, and the problem of velocity determination is limited to gear, chain, and belt ratios. In such machines there may be a variation in speeds due to differences in input or output energy, but the fluctuation is a characteristic of the loading on the machine rather than of the mechanism itself. On the other hand, cyclic non-uniform motion is obtained in mechanisms using cranks, connecting rods, sliders, cams, non-circular gears, etc., and for velocity determination in these mechanisms, the three following methods will be briefly explained and discussed: (I) "Mathematical Analysis," (II) "Vector Solutions," and (III) the use of "Virtual Centres."

I. Mathematical Analysis requires that the displacement of a moving point be expressed relative to a fixed point in terms of lengths and angles, and that the expression then be differentiated once for velocity and twice for acceleration. When this method is applicable, it is usually preferred in industry, as it can give an exact solution (or a close approximation when simplification of formula is permissible), and the actual computations can be turned over to calculators.

However, even for the simpler types of mechanism, the formulae are difficult to set up and only a few examples have appeared in print. An adaptation of the solution given in *Machine Design*, May 1941, for the angular displacement and velocity of the driven crank in the four-link mechanism is shown in Fig. 1.

A good mathematical training is essential to the use of this method, and it would seem that little can be done in the undergraduate kinematics course beyond indicating the basic method and giving an illustration or two.

II. The Vector Solution is a graphical method based on the use of



Let

$$a \sin \theta = W$$

$$a^2 + d^2 - 2ad \cos \theta = X$$

$$X - b^2 + c^2 = Y$$

$$\sqrt{4c^2X - Y} = Z$$

Then

$$1.\ \phi = \tan^{-1}\frac{W}{d - a\cos\theta} + \cos^{-1}\frac{Y}{2c\sqrt{X}}$$

$$2.\ \omega_c = \frac{d\phi}{dt} = \omega_a\left[\frac{a}{X}(d\cos\theta - a) - \frac{Wd}{Z}\left(2 - \frac{Y}{X}\right)\right]$$

FIG. 1. Mathematical solution

vectors in solving for relative velocities and is a direct application of principles usually taught in courses on dynamics. It should be pointed out that the vector method is readily adapted to the determination of accelerations as well. There are three modifications of the vector solution: Transferred Vectors, the Vector Polygon, and the Revolved Vector Polygon or Phorograph.

(a) *Transferred Vectors.* Referring to the solution shown in Fig. 2, BB' is a vector representing the known velocity of B with respect to A. This velocity is resolved into a component BB_1 perpendicular to link "b" and a parallel component BB_2. If b is a rigid link, there can be no relative velocity between C and B in the direction of CB, and therefore the velocity of C when revolved parallel to "b" must be equal to the parallel component at B. A vector CC_2, equal in length to BB_2, is laid off from C along BC. The actual velocity of C (considered as a point in "c") will be perpendicular to CD and hence the vector CC' is obtained from the component CC_2.

The vector for any other point on "c," such as E, is found by proportioning CC' according to the distances of the points from the fixed centre D. Hence, vector EE', perpendicular to ED, is found for point E. This vector is resolved perpendicular and parallel to link "e," giving components EE_1 and EE_2. By the previous reasoning, the parallel component of the velocity of F, FF_2, is made equal in length to EE_2 and from this is obtained the vector

for the total velocity of F, FF', which is drawn parallel to the guides of link "f."

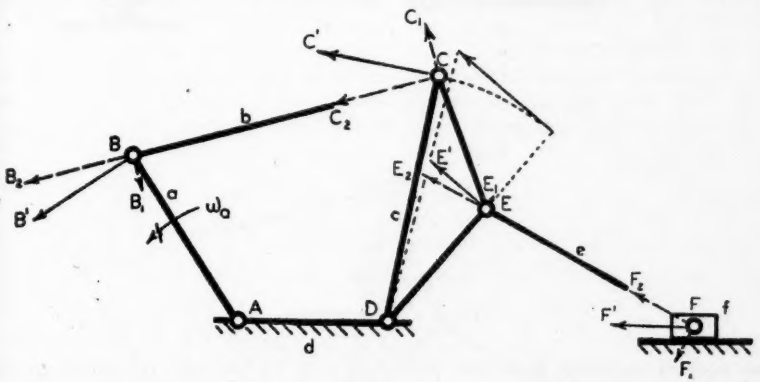
Actual linear velocities are obtained from measuring the vector length and multiplying by the vector scale that was used in laying off BB'. Relative velocity between points not on the same link is obtained by vector subtraction of the vectors representing their absolute velocities. Angular velocity of a link may be determined by dividing the relative velocity of any two points on the link by the distance between the points.

(b) *The Velocity Vector Polygon* is essentially the solution of a vector equation. The equation may be set up with all terms on the left side, equated to zero on the right side, thus giving a closed polygon with the vectors confluent; or some of the terms may be on the right side, giving a polygon in which vectors of absolute velocity radiate from a pole point, and relative velocity vectors join the tips of the rays.

In Fig. 3 the absolute velocity of the point C in the four-link chain a, b, c, d, may be expressed either as V_{CA} or V_{CD} which can be written $V_{CB}+\rightarrow V_{BA}=V_{CD}$. The vector 0–1 is laid off perpendicular to "a" representing V_{BA} to any suitable scale. Only the directions of V_{CB} and V_{CD} are known, being perpendicular to "b" and "c" respectively, but this permits solution of the vector equation with lines 1–2 and 0–2.

When V_C is determined it may be used to find V_E from $V_{EC}+\rightarrow V_{CD}=V_{ED}$. Similarly, the vector 0–4 is found for V_F from $V_{FE}+\rightarrow V_{ED}=V_{FD}$.

Absolute velocities are obtained



Let

1″ of vector $= m$ units of velocity

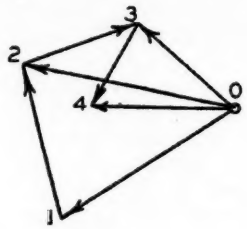
$\overline{B\text{–}B'} = \dfrac{a\omega_a}{m}$ ↙

Then

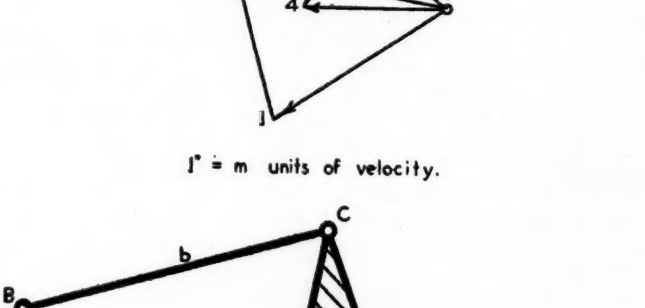
3. $\omega_c = \dfrac{\overline{C\text{–}C'}m}{c}$ ↺

4. $V_F = \overline{F\text{–}F'}m$ ←

FIG. 2. Transferred vectors.



1" = m units of velocity.



Let

$$\overline{0\text{–}1} = \frac{a\omega_a}{m} \quad \swarrow$$

Then

5. $\omega_a = \dfrac{\overline{0\text{–}2}m}{c}$ ↺
6. $V_F = \overline{0\text{–}4}m$ ←
7. $V_{FB} = \overline{1\text{–}4}m$ ↗

FIG. 3. Vector polygon.

from vectors radiating from the pole point 0 by multiplying the vector length and the vector scale. Since the origins of all absolute velocity vectors are at the pole point, vector subtraction for relative velocity can be done directly on the polygon. In Fig. 3, for example, V_{FB} is represented by the line 1–4. Angular velocity is calculated by dividing radius into linear velocity. The angular speed of link "*b*" would be equal to the vector 1–2 times the vector scale and divided by $\overline{B\text{–}C}$.

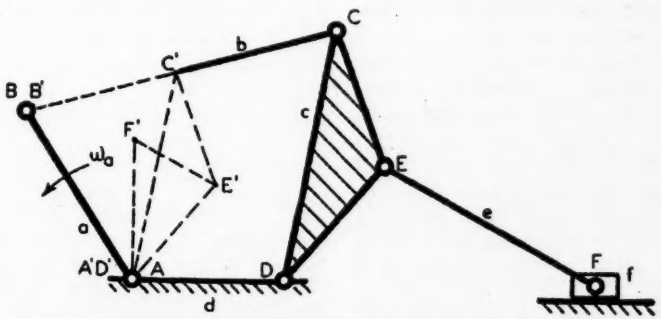
(c) *The Resolved Vector Polygon* is obtained as in part (b) except that all vectors are rotated 90° from their true directions. Hence, the starting vector 0–1 would be drawn parallel to "*a*" instead of perpendicular to it. This makes the graphical work somewhat easier but leads to confusion in

interpretation of the results, due to the 90° shift. Another device, known as the "phorograph" or "motion diagram," may be used to secure the same result by a different approach.

The Phorograph is a pattern of "images" on a plane surface attached to and rotating with one of the links in the mechanism, this link being then termed the "reference link." The link selected for this purpose must have rotation, preferably at known speed about a fixed centre. Images are located on the rotating plane so that they have linear velocities identical with corresponding points in the mechanism.

Images of fixed points are placed at the centre of rotation of the plane since they have zero velocity. Hence, if "*a*" is the reference link in Fig. 4, page 11, the image D' for the point D will be at A. For points on the reference link the images coincide, hence A' is at A and B' is at B. Otherwise an image is placed so that its motion relative to two other images (on the plane) is identical with the motion of the point relative to the two corresponding points in the mechanism. For example C' is at the intersection of a line through D' drawn parallel to DC and a line through B' parallel to BC, since those lines are the loci of images that would have the same motion relative to D' and B' that C has relative to D and B. Because the motion of E is known with respect to C and D, E' is at the intersection of a line parallel to CE through C' and a line parallel to DE through D'. F' is at the intersection of a line through E' parallel to EF (from the motion of F with respect to E) and a line perpendicular to the motion of f drawn through A' (from the motion of F relative to A).

Since the "images" are on a rotating plane, the magnitude, direction, and sense of their absolute velocities are readily obtained from their radii and the angular speed of the reference link. The relative velocity for any two points in the mechanism (not necessarily on the same link) is obtained from the distance between the

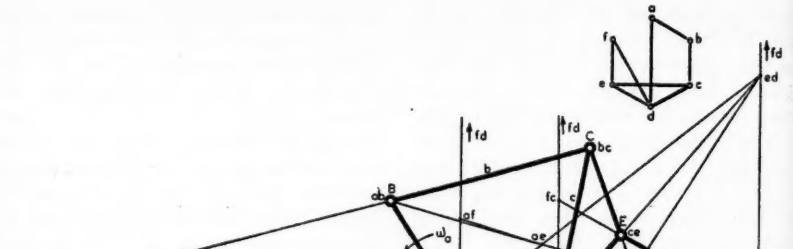


8. $\omega_e = \dfrac{\overline{D'-C'}}{\overline{D-C}}\omega_a$ ↺

9. $V_F = \overline{A-F'}\omega_a$ ←

10. $V_{FB} = \overline{F'-B'}\omega_a$ ↗

FIG. 4. Phorograph.



11. $\omega_c = \dfrac{\overline{ad-ac}}{\overline{cd-ac}}\omega_a$ ↺

12. $V_F = \overline{ad-af}\omega_a$ ←

13. $V_{FB} = (\overrightarrow{ad-af} \rightarrow \overrightarrow{ad-ab})\omega_a$

FIG. 5. Virtual center.

two corresponding images and the angular velocity of the reference plane. Angular velocity of a link is found by dividing the relative velocity of any two points on the link by the distance between the points.

III. Virtual Centers provide another graphical method for velocity problems. The virtual centre or "centro"* is a point common to two links, about which one link rotates with respect to the other. A mechanism of n links will have $\frac{1}{2}n(n-1)$ centros and it is necessary to locate most of these in the solution of a problem.

Permanent centros are easily located at the centres of turning pairs. In Fig. 5 the centro *ad* for links *a* and *d* is at *A*. Similarly, *ab*, *bc*, *cd*, *ce* and *ef* are located as shown. Where the relative motion between two links is pure translation, the centro is at infinity on a line perpendicular to the motion. Thus, *fd* is at infinity on any vertical line.

The location of the centros is found by the theorem of three centres, which states that the three centros of any three links will be on a straight line. Hence the centro *ac* is at the intersection of a line through *ab* and *bc* and a line through *ad* and *cd*. When a particular centro is required it may be necessary to find other centros first. For example, to find *ae*, after the permanent centros are located, it is necessary to locate *cd*, *bd*, and *eb*.

To find the linear velocity of a point on *b* it is necessary to find the

* There are other names for the virtual centre, such as "rotopole" suggested by Prof. de Jonge in *A. S. M. E. Transactions* of August 1943, but these are not in general use for undergraduate teaching.

velocity of *ab* as a point in "*a*" and then obtain the velocity of the specified point by proportion of its distance from the absolute centre of rotation *bd* to the distance $\overline{ab-bd}$. This can be done graphically by compass and straight edge. For the relative velocity of two points, it is probably best to find the individual absolute velocities and use a vector subtraction. The angular velocity of a link is found by determination of the linear velocity of one of its centros and dividing this velocity by the distance between the centro and the centre of absolute rotation.

Centros at turning pairs on the fixed link, such as *ad* and *cd*, have a permanent location. For various positions of the mechanism, centros *ab*, *bc* and *ce* trace out circular paths. Other centros such as *eb* have loci, one in *e* and one in *b*, that form "rolling curves" which are sometimes useful in the design of special gear forms.

The virtual centre method is not difficult to teach in an undergraduate course and is liked by students because the finding of centros is something of a game. However, it is an unwieldy method of velocity determination, particularly in the more complex mechanisms, and does not fit in as well with the needs of industry for a simple, fast and accurate type of solution. It is evident in Fig. 5 that considerable space is required for the solution and it not infrequently happens that centros are difficult or impossible to locate because lines that should intersect are almost parallel. With more graphical construction required, the accuracy is correspondingly reduced.

The virtual centre method has an excellent historical background, and is unique in the construction of rolling curves, but these advantages do not justify its inclusion in an undergraduate kinematics course as the important method of velocity determination.

Because the determination of accelerations is closely allied to velocity work, there is another factor to consider. A method employing centros in angular acceleration problems has been proposed by Professor Koenig in the March 1946 *Journal of Applied Mechanics*. However, the acceleration vector polygon method is likely to be preferred, as it gives absolute and relative linear accelerations in addition to angular values and is not subject to the limitations of the centro method as outlined above. Hence, if the polygon method is to be used for accelerations it would seem more reasonable to use it also for velocities.

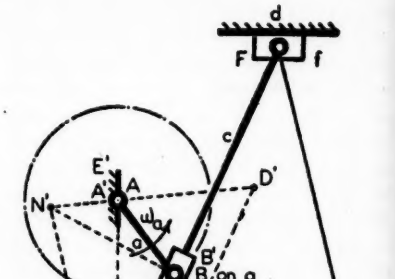
Of the three modifications of the vector method, the transferred vector solution is most readily understood and therefore presents the least difficulty in teaching. Because it places velocity vectors at the actual points where the velocities occur, it presents a better picture of the motions in a mechanism. However, as a tool for velocity determination it is slow and is particularly laborious when a sequence of positions must be considered. Like the virtual centre method, it does not give relative velocities directly and these must be found by additional vector construction.

The vector polygon method offers no great difficulty in presentation to undergraduate students. Although some skill is required to quickly and properly interpret the vector polygon, the development of this skill is not wasted as the polygon method is equally applicable to forces and ac-

celerations and may be considered as a fundamental in engineering. Very little graphical work is required for even a complex mechanism and, as the size of the polygon is controlled in the selection of a suitable vector scale, the resulting accuracy can be suited to actual needs. Moreover, the polygon presents a complete answer for relative and absolute linear velocities from which angular velocities are readily obtained.

For the revolved vector polygon the time saved in graphical construction is not sufficient to justify the increased chance of error in interpretation of results. With the phorograph approach, however, the chance of error is reduced, if not eliminated, and a further reduction in graphical work is obtained through the elimination of the vector scale. Distances on the phorograph are measured to the scale of the mechanism, although in some cases the phorograph is made two or three times larger to improve the accuracy. Presentation of the phorograph principle to undergraduate students is somewhat more difficult, but once it has been mastered, it is preferred by them for the solution of problems.

The phorograph method as outlined will solve any closed four-link chain or combination of four-link chains. Five-link chains are encountered less frequently but may be solved phorographically by use of the auxiliary point method outlined by Professors Ault and Hall in the November 1943 issue of *Machine Design*. Referring to Fig. 6, in which "*a*" is the reference link, the images *E'*, *A'* and *B'* are located as in the original method. Because of the motion of *C* with respect to *B*, *C'* is on a line perpendicular to "*c*" drawn



Method

E' and *A'* are at *A*, being fixed point images. *B'* is at *B* since *B* is on the reference link.

N is an auxiliary point on link *c*, chosen so that it moves relative to *C* as *C* moves relative to *B* and relative to *D* as *D* moves relative to *E*. Then *N'* is on a line through *B'* drawn ⊥ to *c*, and a line ‖ to *ED* through *E'*.

F' is located from *N'* and *A'*
C' is located from *F'* and *B'*
D' is located from *F'* and *E'*

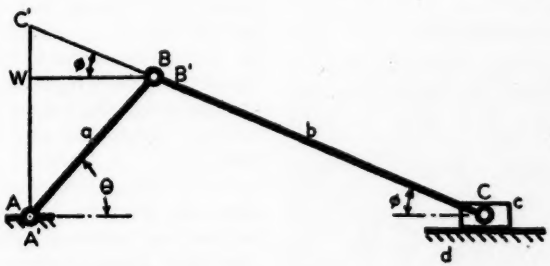
FIG. 6. Phorograph with auxiliary point.

through *B'* and for the motion of *D* relative to *E*, *D'* is on a line parallel to *ED* drawn through *E'*. However, there are no intersecting lines to actually locate these images. Since *D* and *C* are on link "*c*," an auxiliary point is selected on "*c*" so that it moves relative to *C* in the same direction that *C* moves with repect to *B*, and relative to *D* in the same direction that *D* moves with respect to *E*. Such a point is *N*. The image *N'* is then at the intersection of the two lines already drawn through *B'* and

E'. F' can then be located with lines through N' and A' drawn parallel to FN and perpendicular to the guides of "f" respectively. The images C' and D' are easily obtained at the intersections of a line through F' drawn parallel to FCD and the lines already drawn through B' and E'. Thus, when five-link chains are encountered it is not necessary to use a combination of vector and virtual centre methods as suggested in "Kinematics and Kinetics of Machinery," Dent & Harper, and other books, nor is the cut-and-dry method, given by Professor Sayre in *Machine Design*, September 1934, required.

In some cases the phorograph can be used to obtain a mathematical solution where the usual method by differentiation is difficult. For example, the displacement of the slider in a slider-crank mechanism (Fig. 7) takes the form of a $(1-\cos\theta)$ plus a diminishing series. When this is differentiated the resulting expression is usually simplified by retaining only the first term of the series. This gives a close approximation when b is greater than $3a$, but an exact solution is easily obtained by simple trigonometry and the use of the phorograph, as shown in Fig. 7.

If time permitted in a kinematic



From the Phorograph

$$V_C = \overline{A'-C'}w_a \quad \ldots 14$$

But

$$A'-C' = (b+\overline{B'-C'})\sin\phi \quad \ldots 15$$

of which

$$\sin\phi = \frac{a}{b}\sin\theta = \lambda\sin\theta \qquad \lambda = \frac{a}{b}$$

and

$$B'-C' = \frac{a\cos\theta}{\cos\phi} = \frac{a\cos\theta}{\sqrt{1-\sin^2\phi}} = \frac{a\cos\theta}{\sqrt{1-\lambda^2\sin^2\theta}}$$

Substituting in 14

$$V_C = w_a\left[b\frac{a}{b}\sin\theta + \frac{a\cos\theta}{\sqrt{1-\lambda^2\sin^2\theta}}\lambda\sin\theta\right]$$

$$V_C = aw_a\left[\sin\theta + \tfrac{1}{2}\lambda\frac{\sin 2\theta}{\sqrt{1-\lambda^2\sin^2\theta}}\right]$$

FIG. 7. Mathematical solution from phorograph.

course, it would be desirable to teach all of the methods outlined in this paper. However, the importance of velocities in crank mechanisms is not sufficient in relation to the other phases of the work to permit a full coverage. It would seem reasonable, therefore, in order to meet the general needs of industry, while keeping within the limits of teaching requirements, that an introduction to the mathematical method be given and a full working knowledge of one of the graphical methods. It is the author's opinion that either the vector polygon or the phorograph method would be most suitable, with the preference given to the phorograph.

Discussion

The author was very pleased to receive the following discussions when preprint copies were sent to subscribers of the Machine Design Clearinghouse *Bulletin*. These have been arranged in the order of receipt to facilitate printing and, in some cases, have been abbreviated to keep the paper within a reasonable length.

L. C. Price, Michigan State College: Of all the graphical methods which you illustrate, I regard transferred vectors and the velocity polygon as being closest to underlying principles and hence easiest to teach. Of these two, the velocity polygon is to be preferred for reasons which you have given, and for the additional reason that, requiring fewer lines, it gives greater accuracy.

I have long regarded the virtual centre (or centro) method as of only academic interest, having no practical use as long as other methods, so much better, are available.

The phorograph, which is a "trick" method, does have the advantage of convenience. A person who already knows the principles involved and is proficient with velocity polygons will find the phorograph very handy indeed. From a teaching standpoint, however, the principal advantage of the velocity polygon is that it is so perfectly obvious and rests so directly on basic principles. Everybody knows that the velocity of a revolving point B is perpendicular to its radius of revolution. Everybody knows that if BC is a rigid link the only motion which C can possibly have relative to B is rotation about B, etc. It would seem that, if a student is to be introduced to the phorograph as a more convenient method, he should first be taught to use the velocity polygon because of its direct application of principles. Then the phorograph should be easy for him as an adaptation of the fundamental and more obvious velocity polygon.

E. S. Ault, Purdue University: The summary of the various accepted methods of velocity solution is very ably and attractively presented by Professor Smith. He very properly recognizes the necessity for presenting methods that are within the usual student capability and that will develop his powers of analysis rather than to formulate some mere problem-solving method which may be followed mechanically. Some who advocate special methods overlook the limitations of sophomore or junior student capacity and the time available for such instruction in a short course scheduled regularly for all Mechanical Engineering students.

Our experience at Purdue and elsewhere makes us question the author's statement that "the transferred vector solution is the most readily under-

stood." Certainly it is the method most eagerly seized upon by the students but they invariably get into difficulties with directions, because they persist in thinking in terms of *forces* rather than in terms of *directions of motion.*

We have taught the phorograph method and found it the most difficult of the methods to teach. Since that experience we have not used it in undergraduate instruction. We wonder to what extent this method is in use?

At Purdue our instruction develops as follows: In the Mechanism course (5th term) we teach simple relative velocities, the "virtual centre" method, and some application of the "transferred vector" method. Here, in the Dynamics of Machinery Course in the following term, we introduce the vector polygon and use it for velocities, accelerations, and inertia forces. We find that with the preceding methods this gives good coverage and provides a consistent development with sufficient background for handling unusual situations. We employ the auxiliary point method where necessary.

I have never been able to agree with those who advocate the elimination of the "virtual centre" method. Aside from being an excellent pedagogical exercise, it gives a physical conception of motion that is valuable. A simple model helps introduce the idea of the "virtual centre."

L. M. SAHAG, Alabama Polytechnic Institute: *Note:* In an extensive letter, complete with diagrams, Professor Sahag carefully explained a number of graphical methods whereby linear and angular velocities can be obtained by the virtual centre method without resort to calculation. These included the "link to link" method given in Mechanism (Keown and Faires), the method of using the velocity of a centre common to two links (referred to on page 7 of the author's paper), and a method of proportioning angular velocities according to the distances between the common centre and the fixed centros of any two links. For the sake of brevity the various "short cuts" that may be used with the virtual centre method have been omitted from the original paper and from the discussion. However, the following remarks by Professor Sahag are pertinent.

The paper by Prof. I. W. Smith, on "Alternative Methods of Velocity Determination in Mechanisms," is well prepared and the brief explanations of each method should be found sufficient to the teachers interested in the Kinematics of Machines.

As a teacher of the course in Kinematics, I am very much interested in the teaching of velocities and accelerations, and continuously I am striving to make this part of Kinematics digestible to the students as much as possible.

The question as to which method of determining the angular and linear velocities is better, from the student's point of view, is hard to answer. But it seems as if the subject matter is presented in the best logical way, all the methods will be found easy to understand.

But, before the attempt is made, the importance of centros must be well explained. This part, however, is not taken care of so well in the present texts. Some teachers even assert that, to determine the velocities and accelerations, there will be no need of knowing how to find the centros. But, as a part of the Universe, our

conception of motion always conveys the idea of centre of rotation, be this definite or indefinite. Then, again, when we teach the students how to find every centro in a mechanism, we fail to specify as to just how these centros can be used in the solution of velocity and other problems. I have even heard of such expression that in a six-link mechanism there are 15 centros, some are useful, while others do not have any practical value or purpose.

In order to maintain a certain relation between the centros and be able to point out the specific function of each, I have found the following classification of centros very helpful:

Centros are divided into two groups: (a) *permanent*, (b) *virtual*. Both (a) and (b) are divided into two parts: (a-1) *permanent-fixed*, (a-2) *permanent-common;* (b-1) *virtual-fixed*, (b-2) *virtual-common*. All fixed centros are between the frame and the remaining links. For instance, if *d* is the frame and *a*, *b*, and *c* are the remaining links, then *ad*, *bd*, and *cd* are either *permanent-fixed* or *virtual-fixed* centros; while others are either *permanent-common* or *virtual-common*. In Fig. 5 *ad* and *cd* are permanent-fixed, while *bd* is a virtual-fixed centro. *ab* and *bc* are permanent-common, and *ac* is a virtual-common centro. All fixed centros being between the frame and one of the links do not have linear velocities, whereas all common centros between two links have the same velocity in each link. This distinction and clear understanding will not only provide short cuts, but in each method it will help one to find the velocities by a definite rule and more accurately.

In the study of the linear velocities and for the proper design of a mechanism or machine, it is necessary to investigate the variation in the values of relative and absolute velocities for more than one position of the links in a mechanism, because sudden changes in the resulting values of the velocities will cause undesirable inertia forces in the machine parts. If all these investigations are carried out mathematically, the process will be very complicated, cumbersome, and laborious. On the other hand, the graphic solution will not only be practically accurate, but it will be a quick work, and will present a picture which will enable us to tell as to what changes we should make in order that the said mechanism be more efficient and safe. Furthermore, if Kinematics is taught to the second or third year students, then we are more inclined to admit that the graphical solution will be favored by the students.

There can be no doubt that the determination of linear acceleration of points and angular acceleration of links will necessitate the study of the vector or relative velocity method, but time provided for the course, in many cases, becomes the preventive factor in the study of accelerations more thoroughly. For this reason, it will be necessary to have an advanced course in Kinematics, in which complete diagrams can be drawn and studied relative to actual designs.

GEORGE F. BUSH, Princeton University: Having just received the preprint of your S.P.E.E. paper, I am reminded of a small article (copy of which is enclosed) I wrote and which, I believe, describes essentially the "auxiliary point" method of Ault and Hall referred to on page 8 of your preprint. My article is part of N. Rosenauer's work which I have trans-

lated from the German. It may be true that even Rosenauer was anticipated in this "auxiliary point" method.

I shall soon have published another paper on kinematics entitled "Simplified Graphical Solutions for Motions of Machinery." The methods evolve from mathematical developments using vector analysis and may be extended to three dimensions.

Note: The method of Rosenauer as translated by Professor Bush combines elements of the transferred vector method, the auxiliary point, and the instant centre. It is regretted that it cannot be reproduced here, but it may be found in the JOURNAL OF ENGINEERING EDUCATION, Vol. 35, No. 4, December 1944.

PAUL H. BLACK, Cornell University: I think you have made a very fine contribution to engineering education in this paper, both in your opening discussion and in the body of the paper. I have had nine years' experience in teaching this subject at the University of Illinois and nine years at Cornell University, and find that your conclusions are substantially in line with my own feelings. I would sum them up as follows:

1. The mathematical analysis may have advantages for simple mechanisms, as the engine mechanism where an approximate connecting-rod system is used. This is treated very well in "Aircraft Engine Design" by Liston.

2. The transferred-vector method as a general tool lacks so much in comparison with the velocity-vector polygon method that it is not worth while to consider.

3. The velocity-vector method is a simple, fundamental and powerful method and is by far the best method to use generally. As mentioned in the paper, it leads directly to the acceleration-vector method which in turn sets the stage for the inertia-force analysis. Both velocity and acceleration polygon methods lead to special constructions for routine analyses as the Ritterhaus construction. On this basis, a special construction was developed at Cornell University for determining accelerations of the articulated connecting-rod system of a radial engine.

4. While the virtual-centre method does not have extensive practical application, it is worth while to take up in kinematics since it offers a good means for understanding velocities as regards magnitudes and directions. The *conception* of a virtual centre as "two coincident points having no relative motion" is important, even though a complete velocity problem is seldom solved by the method of virtual centres.

5. The phorograph is useful in routine work since lines are drawn parallel to links in the phorograph rather than at right angles as in the velocity-vector diagrams.

6. The author is to be congratulated on this comparative study, and for his insistence that we evaluate our courses frequently in view of the broad requirements of industry.

F. S. ROGERS, Cornell University: Professor Smith's paper concerns itself with methods of teaching undergraduates how to determine linear and angular velocities in mechanisms. In connection with this paper the following thoughts have occurred to the writer:

1. It would seem that our method of solution should be one that a fourth or fifth term student can understand and utilize, but not be

chosen because an experienced engineer has found it to be best fitted to his needs after perhaps years of experience. Our choice of method must be considerably governed by the rather limited amount of time allowed to our student for such study.

2. The method of obtaining velocities should be related to the method to be used in obtaining accelerations; as for example, the velocity vectors should not be drawn at right angles to the localized vectors while the acceleration vectors are to be drawn parallel.

3. Practically any of the methods of construction discussed are successful methods, but there are other considerations of importance equal to the underlying principles of the methods. Among such considerations are: a skillful and conscientious presentation of the topic by the instructing staff, a well written and reliable textbook, a carefully devised system of notation and its incorporation into the presentation.

The instructor must be so thoroughly acquainted with his textbook that he knows what ideas his students are going to get out of it and also what ideas he must add. He must know which are good problems and which are not, how to give quizzes and still more how to grade his papers so that the student gets the best instruction and at the same time he practices the art; meanwhile the student and instructor observe how things are getting along.

4. The nature and proportions of the mechanisms can be made to cause great changes in the desirability of the method of solution to be chosen. When the mechanism used to illustrate the paper is studied it may be observed that a few changes in the shape of the links, or in the way in which they are connected, will make the bad solutions better, the desirable solutions difficult or impossible for our inexperienced student. This again suggests that good teaching is of the utmost importance.

CHARLES THERON GRACE, Iowa State College: I have read the preprint of your paper on velocity determination in mechanisms with interest, especially the section on the phorograph method. I have never tried to teach this method, but feel that it has definite possibilities. I agree with you in your statements about the instant centre method, but at the same time I feel it should be retained in the course as an alternate tool to the vector polygon method. I find it very useful in the teaching of epicyclic gear train calculations along the lines briefly mentioned in "Mechanics of Machinery" by Ham and Crane.

With regard to the vector polygon method as outlined in the paper and in Fig. 3, I find that ease of presentation and the interpretation of the polygon is clarified for the student by the use of lower case letters at the head of the vector to correspond with the point on the original layout of the mechanism. This would of course be confusing in your figure inasmuch as you have called the links by means of the lower case letter. I give the link numbers, always using one (1) to designate the fixed or reference link. Thus, in my accompanying sketch of your problem, the velocity of point B on link No. 1 would stand out in the velocity polygon as the vector o–b, and its magnitude would be found by measuring the length of the vector and multiplying it by the scale factor used for the polygon. I also label

all the images of the polygon by number. Thus, the image of link 1 is the vector o–b and is numbered as link 1 on the polygon. I find it helpful to cross-hatch the image of compound links in the vector polygon just as they were cross-hatched in the layout of the mechanism, see link 4. I do not put arrow heads on the relative velocity vectors since they may be used either way in some latter part of the problem, especially in acceleration analysis. The relative velocity of C with respect to B would be read on the vector polygon as the line b to c (reverse of the vector notation $V_{c/b}$).

I think it might also be worth while in your discussion to take up the graphical solution as given in Ham and Crane and others, in which two of the three scales may be chosen at will and the third set by the relation $k\theta = k_v^2/ks$, as this is very convenient when the problem is carried on into the acceleration analysis.

EDWARD B. PHILLIPS, Cooper Union: The author deserves much credit for his excellent achievement in thoroughly covering the principal methods of velocity determination in mechanisms. However, it seems inequitable that the virtual centre method of velocity determination should be relegated to a place of minor importance and, by implication, should be given only brief coverage in a kinematics course. When we admit that the "first criterion" is that a method should be of general rather than of specialized importance, then the virtual centre method takes a place of more than secondary importance.

In teaching the various methods of velocity determination, the validity of the construction can very simply and conveniently be tested by the use of virtual centres. For example, in the phorograph for the slider crank mechanism, the phorograph is a polygon similar to the polygon of the connecting rod and the radii of points of the connecting rod to its virtual centre. In teaching the vector polygon method, the "vector image" is shown to be similar to the polygon of the link and its virtual centre. In developing the laws which govern the shape of gear teeth for constant velocity ratio, comprehension, by the students, is made easier by use of the virtual centre.

Referring to the author's statements concerning criticism by industrialists—*i.e.*, that young graduates need further training in the special methods used by the organizations immediately concerned—it is vital that the young graduate have at his command full understanding of the fundamental concepts so that we can check the validity of these special methods and gain understanding of them. There is no better aid for this than a thorough grounding in the virtual centre method of velocity determination. The method deserves a place of greater importance than that assigned to it in the paper.

The admitted limitations of the centre method in the determination of accelerations make the polygon method the preferred one. However, a full understanding of the relationship between acceleration of a point and its centre of rotation, instantaneous or permanent, is an aid in the development of the polygon method and in correct interpretation of results.

R. W. ANGUS, University of Toronto: The author has presented an interesting review of the various ways

of finding velocities in mechanisms and has applied each method to the same mechanism. This is, however, only one standard of comparison because there are many cases where, in a particular mechanism, one construction is preferable to another. Everyone who has given instruction in Theory of Mechanism realizes the difficulty of making the subject interesting to students, and the process of solving any specific problem must be such that the student can understand it without undue mental effort and, on the other hand, must be useful in practical work because the students are potential engineers. The writer, therefore, feels that for student instruction there must be a compromise between the convenience of the method used in any case and the difficulty of understanding it.

Of the methods for finding velocities, the writer believes that the classical one employing virtual centres has many advantages, because it connects problems in machines with those in ordinary mechanics and shows that, at any given instant, the motion of a link is the same as that of a line on a rotating disk, a picture well understood by very young students. while it thus forms an easy stepping-stone to the study of machines it is, in general, a rather tedious method to apply in practice, involving the use of a large sheet of paper and accurate drawing. It has much merit, and in such a problem as finding the shape of gear teeth its principles enable the profiles to be determined with relative ease.

Of the graphical constructions, the one adopted in a specific case will depend to a large extent on the user. Some of them are undoubtedly simpler than others, yet the more convenient ones may lead to inaccuracy and improper interpretation if one is not thoroughly familiar with them. The writer has used almost exclusively the Phorograph, first described about thirty years ago in his "Theory of Machines," and used very largely in the book. There seems to be some difficulty in getting students to understand what is, in reality, a simple vector method and the reason may be that the vectors are all displaced through an angle of 90 degrees. Possibly also it is hard to picture an entire mechanism reduced at any instant, as far as motion is concerned, to a series of lines on a single disk rotating about a central point, yet this is just what the virtual centre shows, but in a slightly different way.

The name is somewhat of a stumbling block, adding an air of mystery to those not familiar with its derivation, and the writer has discarded it in favour of the better understood "Motion Diagram." The construction is readily applied in practically every case, can be worked on a small drawing board, and the scale may be changed so as to magnify any point desired. It is also useful in obtaining accelerations.

The writer has not found many occasions where the mathematical method was necessary, as the graphical constructions give results quite well within the range of accuracy desired. If greater accuracy is required the graphical solution can be made and the triangles involved may be solved with little knowledge of mathematics. Mathematical solutions do, however, show the effects of the various harmonics entering the motion and may be a guide to a designer, so that to some extent they must be included but, in the writer's

experience, students do not take kindly to them.

There has been a tendency of late in this science to depart from the classical methods which, though sometimes uninteresting, have been of great value in a clear understanding of what properties a particular mechanism has, and the writer hopes that the younger men like the author will not be so anxious for ingenious constructions that they will forget the basic principles.

Following presentation of the paper at St. Louis, there was considerable discussion from the floor, an account of which has been taken from the secretary's report:

S. J. Tracy, City College of the City of New York—considers that all methods should be used to develop the student's mind.

W. A. Johnson, Cornell University —considers that the use of the transfer vector method leads to the confusion of the student—recommends the use of the velocity vector method and placing the velocity vector directly on the mechanism, which is useful for absolute and relative angular velocities

—suggests that the Phorograph method has not been developed very far due to possibilities of wrong methods being used by students

—suggests teaching all methods.

J. H. Billings, Drexel Institute of Technology—has used the Phorograph method in his teaching for 25 years and has found it very satisfactory, practical and useable on all mechanisms

—he also finds it very useful as an introductory method in work on accelerations.

L. C. Price, Michigan State College —suggested that the use of the velocity polygon fits in with the solution of vector equations and hence was a desirable method on that account.

E. R. Wilson, University of Akron, and A. L. Thomas, Alabama Polytechnic Institute—both spoke in favour of the velocity vector method.

Teachers Are Human Beings*

By CHARLES E. GUS

Professor of Engineering Mechanics, New York University

Teachers are human beings, or should be. Starting out from this point of view, there are a few ideas that I would like to present which may be helpful to those of us who are interested in teaching techniques and may perhaps be of value to those who are just beginning careers in teaching. Volumes have already been written on this subject; many more could be written; and there is an inexhaustible supply of points of view that could be discussed. However, for present purposes we can limit ourselves to the following ideas:

1. The need for teaching with authority.
2. The students' point of view and his mental equipment.
3. Special techniques such as visual aids.
4. Correlation of teaching with everyday living.
5. Future problems in developing good teachers.

The teacher should teach with authority. His statements, his attitude in the classroom, and all his dealings with the students should continuously convey the idea that he is a master of his subject. Bluffing must be avoided like poison. It is, of course, impossible for most individuals to know everything about all things; and the students will be willing enough to admit that instructors have typical human failings provided the instructor has sufficient mastery of his subject to convey the impression to the student that he is tremendously ahead of the student in the understanding of the subject and therefore suited to guiding the student towards substantial achievement. This authority that is inherent in mastery of the subject matter can only be developed by "living, eating and sleeping" the subject matter itself. To use my own field as an illustration, very few of us, even if we received the grade of "A" in our college courses in strength of materials, would be able to go into the classroom and teach this subject effectively on the basis of what we learned during the college course. Even with the additional advantage of having taken advanced or graduate courses, we would still find ourselves away below par in giving an effective undergraduate course in resistance of materials. Mastery of the subject matter in any course seems to be a matter of digesting many text books on the subject, of working hundreds upon hundreds of problems, and of practicing faithfully and continuously on every element of the course until it becomes second nature. The analogy of learning to play the piano is not too far

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fetched. Monotonous daily exercises over and over again with a will to achieve mastery and with the spiritual desire to become an accomplished pianist are elements which, when fused together, will probably produce the desired results. The same is true in learning to teach effectively. It is difficult drudgery for the first few years and a hopeless undertaking unless one is willing to do countless "five-finger exercises" of working problems and of becoming familiar with every little snag that might show up during the actual presentation of the course. Above all, one must be impelled by the desire to take the cold facts out of the text book and transform them into vital ideas capable of absorption by the student.

There has been a tendency to scoff at formal courses in educational techniques and psychology and philosophy of education. These, however, can be of great value to the young teacher provided he is well on the way towards acquiring mastery of his subject matter and provided that he has the patience that is implied in this discussion. Probably we have scoffed at the courses in educational methods because we have met individuals who know all the methods, but had no subject matter to present. However, the teacher who is a master of his subject matter and keeps abreast of educational techniques, as developed by research in this field, is a valuable man indeed. I cannot emphasize too strongly the necessity for mastery of subject matter and I rather feel that this can be made deeper or more intense if the young teacher does not specialize too early. Most of us who are wearing our hair gray these days began our teaching careers at a time when teaching fellows or graduate assistants were shared by several departments. I can recall with much pleasure the fact that I was called upon to teach analytic mechanics, kinematics, electrical engineering, hydraulics, calculus, and a few other odds and ends. Others of us who had this experience know that it helped us to develop mastery of the subject matter in which we finally specialized because we could appreciate its interrelation to the remaining engineering studies. At the present time when teaching fellows or young instructors are hired specifically to teach mechanics or hydraulics or some other specialty, there is great danger that they may develop in that restricted field without appreciating its relation to the rest of engineering science. At the risk of cracking a very ancient joke, I am reminded of the young M.D. who went to his family doctor and said that he wasn't going to waste his time with general practice or even with general surgery but was going to specialize in one particular field immediately—in fact he had decided to become an expert on the human nose. The family doctor thought for a few minutes and then very softly replied, "Yes, my boy. Which nostril?" This, of course, is gross exaggeration, but it represents a modern danger in engineering education. I am inclined to bet more heavily on the versatile teacher who ultimately becomes a specialist than on the man whose every teaching effort is in one particular field. So much for the time being for the instructor's mental equipment.

The mental equipment of the student is also important. Even though we pride ourselves on the high degree of literacy in America, the fact remains that instructors who are selected from the most promising of our college graduates will, in general, be much more literate than their students and,

unfortunately, if the instructors do the studying and reading that they should do, they run the risk of becoming "too darn literate." Many a young man of brilliant mental attainment has been unsuccessful as a teacher because he and the students were not speaking the same language. The batteries of entrance tests that are becoming so popular for hazing the Freshmen before they enter college do actually succeed in selecting classes of young men who are well qualified to profit from college education. However, high school cramming, high school social activities, the movies, and frequently the need to be partially self-supporting do discourage the art of reading which means that our typical college classes neither read as well as they should nor have the wide vocabulary that results from reading. In discussing this matter with colleagues in arts colleges and in theological seminaries, I find that many of them are appalled by the decreasing ability to read, mark, learn and inwardly digest. This should not be construed as criticism of the students. They are willing and eager to learn; but it does impose upon the instructor the obligation to use the English language rather than technical jargon and, although he need not descend to baby talk, he may be required to state his thoughts in extremely simple language. This effort to express his thoughts in simple language will frequently sharpen and refine the instructor's thinking. The instructor should also realize that idiom changes almost from generation to generation. He need not be undignified, but should obviously not be ignorant of the fact that there are such things as "hep-cats" and "rug cutting" and that there probably will be equally startling slang phrases in ten years to come, by which time "hep-cat" may be enjoying a dignified niche in the dictionary. The instructor needs to digest his subject matter, break up into units that are suitable for student assimilation, clothe these units in the simplest possible language, and, from time to time, spice the presentation with some of the current idioms.

Granted adequate mastery of the subject by the instructor and the ability on the part of the instructor to understand the students' method of thinking, the presentation of most subjects can be improved tremendously by use of visual aids. There is no need to discuss this at length because we have already had an extremely interesting session dealing almost entirely with visual aids and there is every reason to suppose that developments in this field will continue to be a feature of S.P.E.E. gatherings. In spite of much publicity to the contrary, I am not too much afraid of ever walking into my classroom to find myself displaced by a motion picture machine and a loud speaker; but visual aids can be used as a valuable supplementary feature in most presentations of scientific material. Motion pictures and animated cartoons are quite useful and naturally attract the greatest amount of attention. There is, however, a noticeable trend among educators in all fields to prefer carefully prepared still pictures with appropriate descriptions. These descriptions may be delivered by means of phonograph records or read from script or delivered extempore by the instructor depending upon his ability. I have had some reasonable success with home-made amateur animated cartoons to illustrate certain tricky problems in dynamics and kinematics. These can be made economically in your own laboratories or offices and, in

my judgment, are always superior to the professional product if they are made to fit the presentation that you have developed. There is no sense in discussing methods of preparing animated cartoons now, but I would be glad to discuss it with anyone who is interested. I feel that visual aids belong in the same classification with formal courses in educational psychology and educational techniques. They are necessary equipment for the competent instructor, but they can never replace the fundamentals of mastery of subject matter, understanding of the student's mind, and effectiveness of presentation.

Another feature in effective teaching which must be considered is the necessity for correlation of a man's teaching with everyday living. Attention to this factor will prevent the instructor from remaining in the year 1923, or whenever he graduated, while he lectures in succession to the classes of 1947, 1948 and so on. The instructor should be alert to all developments in his particular field. If it happens to be in engineering mechanics, he should bring into his lectures at the appropriate places some pointers on new bridges that are being erected in the neighborhood or on new developments in automotive, railroad, airplane, or other methods of transportation. To do this sort of thing successfully he should have a lively interest in engineering developments and in his early days should have frequent contacts with actual industry in its significant phases. These contacts should not be abandoned as he grows older, but they will need to be modified because, as all of us know, the requirements imposed upon older teachers by our institutions involve much more far-reaching responsibilities than are required in our younger days. Correlation of teaching with everyday living should not be limited to engineering or science. There is no reason for converting a lecture into a news broadcast, but it is not amiss to call attention to one or two current news items from time to time. Repeatedly there will be news items reported in the papers that will illustrate something connected with the presentation of the course; or perhaps the rigid application of some principle of the course to a political occurrence will show up the fallacy in that political situation and will help clarify the students' thinking about citizenship. Also, from time to time, the bearing of a particular principle of analytic mechanics upon matters of philosophy or ethics may be important.

Most of us who belong to the older generation have arrived at a reasonable degree of proficiency in teaching by luck or evolution or something or other, but when we look towards the future we must face the fact that there may easily be a great scarcity of effective teachers in ten or fifteen years' time. This will arise from increased application of big business methods to our engineering colleges and the S.P.E.E. could easily save education from this fate if it realizes the dangers that we are up against and faces them courageously. A glimpse into the past will be interesting. In the middle ages effective teachers took up residence in centers of learning and the students flocked to sit at their feet. Albertus Magnus, who was a German, lectured in Paris during the thirteenth century and students flocked to hear him from Italy, England, Spain and other parts of the world. They were not attracted by the research projects that were under way at the University of Paris, they prob-

ably were not particularly interested in whether Albertus was doing significant research or not. Naturally, he was doing research in his field in order to develop his teaching, but the students flocked there because he was an effective teacher and he had much to offer. It is inconceivable in this modern day and age that students would flock to hear any professor if it involved crossing national lines and national boundaries. Furthermore, research has come distinctly to the front of the picture. Recently at a meeting of the Executive Committee of our College of Engineering, one of my colleagues made the comment that research was the major activity of the College and he added as an after-thought that anyone could do mere teaching. I am not criticizing him in any way because he is a man of tremendous ability and judgment and he is right in maintaining that research is a very important activity of any college, but his comment shows how far we have come from the day when Mark Hopkins, one student, and a log constituted the ideal university. Many of us would do well to reach into our bookcases and take out an ancient volume and read what Cardinal Newman had to say on the subject of the ideal university. It is very easy to overemphasize research and we all know that the young instructor has a great tendency to look towards a career in research rather than in teaching because it appears to him that advancement in rank and remuneration comes quickly that way. This is controversial territory; I am not decrying research because, like so many others, I have done my share of it. But I know how easy it is to over-emphasize research and I am hoping for the future that corresponding emphasis will be placed upon the development of good teachers. Young men who show promise of developing into good teachers should be encouraged to develop the characteristics that have been discussed in this paper; and their early classroom activities should be supervised either by the department chairman or by the member of the department who is best suited temperamentally to do this type of work. They should be encouraged to take courses in educational methods, they should be encouraged to do research in the development of educational methods, which is itself a very dignified and necessary form of research. If, with the passing of time, it becomes evident that they have the makings of a good teacher, they should be encouraged to bend all their energies in this direction. Most important, college authorities should recognize more fully than they have ever done before that there is a growing need for professional educators and should have definite plans for promotion and remuneration that will attract the best men to this type of work. In the days to come we are not going to have effective teachers unless those of us now teaching spend time and energy in developing a new crop. The days of hit and miss have vanished. We must grow our new generation of effective teachers and we must pay them adequately.

Aims and Content of Under Graduate Courses in Machine Design*

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There are certain qualities and characteristics found in some courses of the engineering curriculum that make them towers of strength around which other courses tend to revolve. In the mechanical engineering curriculum, thermodynamics is generally one of these, and a place is regularly found for it in the curricula of other departments. Machine design, from its broad relations with other subjects and its inherent importance in a machine age, should similarly occupy a stellar place. Where it does not, diagnosis and treatment are in order.

It is the purpose of this paper to explore some of the qualities that a course in machine design must have to fulfill its destiny as the hub of those mechanical engineering courses which fit engineers to make things.

My general philosophy may be summarized by the statement that where machine design courses are on the defensive, it is because they are too specialized on the one hand, and, on the other hand, where too little attention is given to making them vehicles of broad education, thoroughly and intimately based on those fundamentals of science which it is the main duty of engineering colleges to teach. I realize that this philosophy is controversial, but I also recall Chairman Young's expressed desire that discussion in these sessions be stimulated.

The following aims and objectives are tabulated to facilitate reference and discussion:

A. Primary Aims

1. To extend the student's knowledge of the construction, functions and operation of machines and mechanical equipment.
2. To develop and sharpen the student's grasp and working knowledge of mathematics, physics, mechanics and strength of materials, and to broaden his knowledge of the materials of engineering.
3. To teach the selection, application and maintenance of machines and mechanical equipment.
4. To educate the student in the design and development of machines.

B. Secondary Aims

5. To enlarge the student's knowledge of production methods and fabrication techniques to the end

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that he can design things that can be manufactured.

6. To make the student cost-conscious, to develop economic sense.
7. To discover and stimulate ingenuity and inventive talent.
8. To orient the student in the fields of mass production and standardization.
9. To make the student aware of the contribution that the industrial artist can make to his design.
10. To develop such natural endowments as common sense, imagination, and judgment.

The first four aims are starred by the distinction "primary" and the order is intended to be that of importance. Some doubtless may contend that the tender is ahead of the locomotive with the caboose leading both. Let us first look at the evidence. The course, at least the first course if a series, is to be given to all mechanical engineers and perhaps to electrical engineers and others. A small percentage of these will make the design and development of machines a major part of their life's work and no one knows which ones. All who follow engineering in almost any line of work use machines, instruments and mechanical equipment. Even if they never design a machine, they need an understanding of the construction, functioning, possibilities and limitations of machinery, which the design approach most effectively gives.

The second aim might well be given first place. The industrial leaders in the larger companies who are charged with the formulation of the educational policies of those companies have been most vociferous in recent years in calling for a better job of education in the fundamental sciences. I quote from an article entitled "Reply from Industry to the Colleges" by Boring, Stevenson and McEachron appearing in *Mechanical Engineering* for August, 1945.

"Engineering education in college must be concerned with engineering fundamentals rather than specialized design. The war has shown us that radically new designs must usually be based on fundamentals of engineering rather than on previous design. It is far more important, therefore, for the college graduate to have a thorough understanding of all the fundamentals underlying engineering rather than detailed knowledge of any specific design or device."

The voice of industry has never been unanimous on this point. What engineering college has not been beseeched on occasion to institute degree courses in air-conditioning, diesel engineering, electronics, tool engineering and many other quite important sectors of the engineering field. It is fair to say that these requests generally resulted from understandable local enthusiasms and seldom did they measure the considered opinion of the majority of engineers in industry. While I do not subscribe to the infallibility of our brothers in industry on educational matters, I think the majority is right on this point.

A very pertinent question arises here —Why include any application courses in undergraduate engineering if education in the fundamental sciences is the preeminent objective? There are, I think, two reasons. First, no better way has been discovered to make mathematics, physics and mechanics thoroughly comprehended than by applying them to the solution of practical problems. In no other way can the learning processes be made so interesting, even enjoyable. To apply a principle is to know it with an understanding and

a security impossible upon the first approach experienced in the initial course.

In the second place, the application courses prepare the student to enter a profession. They must open before him the literature, the sources of information, the codes and the accumulated experience of the profession. At best, they take a partially trained scientist and turn out an engineer-in-training, ready to go a long way under his own atomic energy.

The third aim, dealing with selection, application and maintenance, is of primary import because there are few sectors of engineering work where problems of this sort do not arise. Other courses, such as machine tools, shop lay-out, power plants and shop courses, furnish education on this theme, but machine design offers the direct approach and the experienced teacher will find many opportunities to show his students that it is not individual machines, but a well-integrated shop with planned maintenance, that gets production results.

Most of the other aims mentioned have received attention at past meetings of this society. I recommend for your review, "The Objectives of Instruction in Machine Design" by Garland and Weibel, presented at the annual meeting of this society in 1940; "Machine Design Instruction in the Post-War Period" by P. H. Black given at the 1944 meeting; "Teaching Engineering Judgment" by C. Higbie Young given at the 1945 meeting; and "Developing Creative Engineers" by J. F. Young appearing in *Mechanical Engineering* of December, 1945. The issues of the Machine Design Clearinghouse *Bulletin* provide a running commentary on the desirable objectives of our work.

I should like to comment briefly on aim number 7, dealing with ingenuity and inventive talent. Many of our students were initially attracted to engineering because they recognized that it is essentially constructive, creative. With a super-abundance of the urge to make new and better things, they enrolled as freshmen in our engineering colleges. Then, say our critics, we proceeded to do strange things to them. We shaped their heads into funnels and poured in tons of facts, relations and derivations, giving them neither time nor opportunity to have any creative output until they forgot that they ever had the urge to invent. The worst thing about this accusation is that there is more than a grain of truth in it and from the nature of our present mathematics and science there is not much that can be done about it for the first two years of the course in engineering. The answer is to be found in the application courses and particularly in machine design. In our course at Drexel Institute of Technology, we insert in each chapter at least one problem where the student can chew his pencil and invent. I know that many of you are evolving unique solutions to this important problem and we should like to hear about them.

The content of machine design courses must depend on the general framework of the curriculum. It is most desirable that the foundation should include mathematics with an introduction to differential equations, physics, mechanics, the shop courses, materials of construction, and strength and elasticity of materials. In the cooperative colleges the student will have punched the clock in several production shops, possibly followed by design room experience. In the other colleges, summer jobs may have supplied this invaluable background. Those of us

who have experienced the late, unlamented acceleration courses have no uncertainty about the value of industrial experience as a prerequisite to machine design. The above preparation will generally place the first course in machine design not earlier than the last term or semester of the junior year.

There is another group of courses closely related to machine design which should desirably precede it. First of these is metallurgy and metallography, vibrations, and the courses in strength of materials laboratory. We have found that three hours of class work and three hours of concurrent design-room practice per week, running through two terms, is a reasonable allocation of time for mechanical students with half that time for students outside the Mechanical Engineering Department.

Probably no engineering course affords a wider choice of content than machine design. There are, however, certain essentials without which the presentation of the subject will be obtuse. Of first importance in the lecture course is stress and strain analysis. The strength of materials course will have laid the foundation and the first task is to establish the bond for future building. We find that a review of the derivations for principal stresses including the Mohr circle is essential. This makes the general solution for the three dimensional stress system less difficult. Until the student feels secure in evaluating the three principal stresses and the grand maximum shear stress and in locating the planes on which they act, much of the literature in applied mechanics is, for him, a closed book.

The maximum stress, maximum strain and maximum shear theories of yielding and their application is the next topic. The distortion-energy theory should receive some attention due to its accuracy in predicting the performance of the ductile materials. Next come fatigue of materials and stress concentration. Coverage here should be unhurried. The foregoing topics seem to be the ammunition necessary for a frontal attack on factors of safety and allowable working stresses.

Design for limiting deformations receives much attention, both in class and drafting room. The wide application of the resistance-wire strain gage and its future possibilities would seem to justify more attention to the theory of the strain-stress relationship at the expense of some other topics.

The order of content from this point forward can vary widely, being influenced generally by the requirements of the early problems used in the design room. I feel impelled, at this point, to give a morsel of advice. Don't try to cover too much. Covering machine design is like trying to carpet the ocean. One topic dissected from root to branch has more educational worth than chapters of empiricism. Of course, the student should learn how to use handbook and catalogue data and be familiar with the sources of recorded experience. That is best taught in the design room and the time devoted to it need not be large.

Our experience is that the most fruitful classroom procedure for a chosen topic is—(1) theoretical analysis, (2) collection and study of pertinent codes and experimental data, (3) practical and economic considerations, (4) illustrative and assigned problems. Doubtless there is nothing new in this procedure but the point I wish to make is that topics not sufficiently developed

to be out of the empirical design stage are not worth serious consideration in a design course. Another point concerns the statement all too frequently found in textbooks on machine design which begins with the words "It can be shown that . . ." followed by a formula which the student, and sometimes the hapless instructor, is supposed to use without an inkling of its genesis or limitations, or whether it is based on an established scientific law or resulted from experiment or practice.

The possible coverage of journal bearings might serve as illustration. A good theoretical approach is the setting up and solution of the differential equation for oil pressure and flow through the simple slipper bearing. This is a satisfactory introduction for the study and application of journal bearing theory as developed by Kingsbury, Howarth, Needs and others leading to rational determinations of load capacity, clearances, friction, cooling and oil supply.

To give the student a sense of accomplishment in stress analysis and to open to him a considerable field of literature, there are few better topics than Lame's equations. In deriving these equations, a perfect differential equation of moderate difficulty displays the assumptions and limitations. The road is now open to many interesting and useful applications in design—thick cylinders, gun tubes, press and shrink fits. These equations also afford a beautiful demonstration of the effect of placing a pin hole in the center of a disk subjected to centrifugal forces. At this point, not a few students admit that, for the first time, they see some sense in differential equations.

I have no desire to advance the proposition that involvement in differential equations is the first criterion for selecting good machine design topics. I do contend, however, that the course which avoids the use of this sharp-edged tool fails in achieving one of its primary objectives.

For the concurrent program in the design room, we believe in more design than drawing without the exclusion of the latter. The early part of the course seems to require simple projects suitable for three to nine hours of work. An example is the design of a bracket to be screwed and doweled to the vertical wall of a machine and the support a horizontal shaft in a cylindrical bearing. The specification includes load and maximum allowable deflection under load. The bracket is designed first in cast iron, under rather close control by the instructor. Much instruction is necessary, particularly in foundry practice. The next assignment is the design of a weldment of structural steel parts to meet the same specification. Here there is no control and not too much advice, but codes and examples of welding design are provided. Some wonderful and fearful brackets result, but the poorest are useful as a basis for teaching the art of welding design and the students have an inventive experience.

We make a point of requiring the student to use a computation book according to approved design-room practice. The righthand page contains an orderly record of data, assumptions, computations and approximations, with significant results in a ruled margin. The left page is for sketches and all preliminary scratch work of the kind that would otherwise go into the waste basket but is often useful if preserved.

In the design room the student should learn much about the sources of design data, about handbooks and standards, about the small important

things such as connectors and alignments. Here the good instructor, with a background of practical experience, is worth his weight in master gages.

Rare judgment is required to draw the line between getting good designs and allowing the student to learn from his mistakes. When a student has designed a speed reducer using integral shaft and gears and finds that it would take a magician to get the shaft into the gear box, he is being effectively shocked into an education. He cannot be given that experience in the classroom.

Finally, there are two considerations which cannot be neglected at this time in any appraisal of desirable education in machine design. The prospect of cheaper and more abundant power from fissionable material points to the possibility of rapid development in many fields where excessive power demands have previously prevented economical design. Also, this nation has a well established reputation for fast and prodigious production of new designs, a capacity we must preserve at all costs. It would appear, therefore, that if we aim only to educate for the solution of specific problems, we shall miss the target. The best machine design course is one which prepares the student for the development of equipment unlike any he will probably hear about before graduation day.

Discussion

K. E. Lofgren, Cooper Union: Professor Billings has admirably presented a paper which offers much food for thought and discussion. There is so much of it that one must agree with and thank him for voicing that it is hard to offer constructive criticism. In some respects I have the belief, however, that it leans somewhat towards the ambitious side. Perhaps this is a wholly desirable position, but I fear that it does not consider adequately the student. In short, I do not believe that our average engineering student has the mental capacity and maturity to assimiliate, in the short time available for machine design, the type of study proposed.

There is danger in placing too much emphasis on the intricacies of the theory of elasticity in an undergraduate course. First of all, it places in the student's mind an unwarranted dependency and bland faith in the formula as a major design tool. Too often, our students produce ridiculous designs due in great part to their naive faith in formulas. They are slaves to theory and slide rules enough as it is, without aggravating it by giving them more of the same.

Not every engineering graduate is going to be a machine designer nor every machine designer a stress specialist or a research engineer. There is a large amount of important design work done with a minimum of computational work and I am sure that in many industrial drafting rooms there are comparatively few stress analysts.

In the short time we have for our machine design work in an undergraduate course, I would want to spend more time in discussing the limitations of our formulas than in derivations of them. At The Cooper Union we ask our students to make the calculations for all the machine elements they design. But before the resulting values are translated to the drawing board, we compel them to make severe modifications. This takes a lot of explaining. You have to be quite convincing in order to make a student change the diameter of a speed reducer shaft from a computed diameter of one inch or so to a final diameter of two inches.

This does not mean that we ignore the derivations of formulas. I think it

is desirable, for instance, to cover the derivations of Lame's equations, for otherwise you could not very well expect the student to differentiate them from their cousins, the Clavarino equations. But I do not expect my students to become experts in such derivations, for while the theory involved is interesting and beautiful, rarely does actual design require the use of these equations. Even the A.S.M.E. Unfired Pressure Vessel Code does not make use of them. And as an aside, I yet have to find any theory that we can teach our students which will help them to understand this code.

Our men have a separate course in mechanics of materials in which the theory of elasticity is well covered, hence in our Machine Design work we feel that our job is not to repeat this, but to give the students as much practical application of it as time will permit. The more advanced work in stresses deserves the greater maturity and time available in graduate courses.

B. E. Quinn, Purdue University: In determining the aims and content of undergraduate courses in machine design, let us consider the experience of a young design engineer, fresh from the campus. He has taken more machine design courses than his classmates who have entered other fields, and for this reason he has confidence in his ability. He enters the company as a new employee and therefore is not familiar with the older men who are willing to guide and advise him. His assignment is outlined by his superior, and the young engineer realizes that it is totally unlike any design project considered in the classroom. As soon as possible, he carefully examines all the available texts in machine design, only to discover, with a sinking feeling, that the solution to his particular problem does not lie therein. Perspiration comes to his brow when he realizes that the texts have failed him, and because he is far from his campus he must solve this problem by himself. The solution must come from him; he is his only resource! The realization of this fact comes as a shock of the first magnitude.

Let us consider the training which he should have to meet successfully this situation.

(1) He should know that his experience is not unique, but that many other engineers, both young and old, have encountered a similar situation.

(2) After carefully studying the problem, he should recognize certain details with which he has had previous experience.

(3) He should realize that further study is necessary to deal with the unfamiliar portions of the problem, and that such study is the beginning of his specialized training which will *not* be in the nature of formal course work.

Would the type of machine design course, outlined by Professor Billings, be valuable in this situation?

In his paper, "Aims and Content of Undergraduate Courses in Machine Design," Professor Billings has carefully outlined the characteristics necessary to make these courses of greatest general educational value in the engineering curricula. He has shown that a carefully organized course in machine design can be of great value in developing the student's ability to use his knowledge of physics, mechanics, strength of materials, and other subjects. In this manner a course in machine design may serve to integrate previous learning for a student who is

primarily interested in other aspects of engineering. To do this, however, does not decrease the value of the course to those who are primarily interested in machine design. It is the ability to apply the engineering fundamentals to the new problem which the young engineer so desperately needs in the situation just described.

In order to give comprehensive training to young engineers interested in design, it is becoming more evident that creative ability should be stressed and developed. When faced with a new problem, it may be necessary for the engineer to create the machine which is required. This may necessitate the selection and arrangement of the mechanical elements of which the machine is composed. Only after this important and fundamental step has been taken, is it possible to make any computations for determining the sizes of the required parts. Adequate training in machine design, therefore, requires training in all phases of the science. The problem of developing this creative ability in the young engineer, discussed by Professor Billings, may require specialized training similar to the advanced mechanical design course, which A. R. Stevenson, Jr., of the General Electric Co. has developed.

In closing, it might be appropriate to mention briefly some desirable qualities of advanced training in the field of machine design. A course * of the type recently described by Professor P. H. Black of Cornell University in the April, 1946 issue of the *S.P.E.E. Journal* would acquaint the student with modern engineering developments of value to the design engineer. A familiarity with differential equations, including a knowledge of their uses and limitations, would be of great importance. To facilitate and encourage the use of these equation, the engineer should be trained in the graphical methods for obtaining solutions. These methods may save considerable time when a general analytical solution, available only after hours of labor, is not required. The results of investigations in applied mechanics should also be made available to the engineer specializing in design.

It is naturally obvious that a certain amount of detailed information must be included in any course in Machine Design which obtains a specific solution to a given design problem. Economic design through the use of standard parts is a well recognized goal. The need for this detailed information, however, should not obscure the engineering fundamentals upon which the properly organized Machine Design course can occupy a position of great significance in the engineering curricula.

Discussion from the Floor

W. A. Johnson, Cornell University —intimated that mechanical laboratory experiments on belts, sleeve bearings, stress (photoelastic), etc., were disappearing from their curriculum—agrees that design literature, etc., should be available to broaden the experience of the student—suggested that when students come to machine design they already have a dislike for drawing and have already decided that they do not want to stay on the board.

L. C. Price, Michigan State College —suggested that machines were becoming too complicated for students to understand easily—comparing past and present automobiles.

* "An Experiment in Course Administration" by Professor P. H. Black, *S.P.E.E. Journal,* April, 1946.

E. S. AULT, Purdue University—stated that students must spend eight hours per day for two weeks in a summer course in their machine shop and a similar time in their mechanical laboratory dealing with bearings, belts, pipes, etc.

C. HIGBIE YOUNG, Cooper Union Institute—stated that it is planned to have all engineering groups, following the completion of the first year, spend eight hours per day for eight weeks at camp where the instruction will cover surveying, field practice, mechanical shop, humanities and physical exercise—stated also that in the mechanical shop program the problems will be given with little information which will require the student to set up a procedure of his own.

D. K. WRIGHT, Case School of Applied Science—stated that they require students to take survey camp at the end of their first year, and shop course following their second year or suitable industrial experience (at any time).

Engineering Education in the Future*

By ALEX D. BAILEY

Commonwealth Edison Co., 72 W. Adams St., Chicago 90, Illinois

I thought I would take a new approach to this problem and approach it from the engineering profession angle; consequently, the title of my talk might be *The Engineering Profession Grows up, and What are Engineering Educators Going to Do about It.* There can be no question but that the conception of the engineering profession, its scope, obligations, etc., has undergone many changes in recent years. Engineers are assuming new obligations and accepting responsibilities in fields far removed from technical work. The public is generally accepting the broader view of the engineer's responsibility, and he is coming in for more criticism if he fails in performing these new duties. The engineer himself has learned that the engineering education which he received, the habits of study and the training which he acquired can be put to good use in the much broader fields than those purely technical, and that he can hold his own with representatives of the legal and political professions; he is acquiring tact, he is becoming more politic in his thoughts and actions and is realizing the importance of human relations in his chosen profession.

There are so many evidences of this trend that it might be well to enumerate some of them: If you are following engineering literature, particularly the magazines of our founder societies, and even the publications of this organization, you will find an increasing amount of space devoted to subjects which are not technical. This, it seems to me, is recognition of the trend referred to, and the need for education outside the purely technical field. While there has been some resentment from some engineers toward this change from purely technical subjects, I am sure that this resistance is decreasing and that engineers generally will accept the idea that an engineer must be much more than a technician or a mechanic if he is to properly represent his profession. We hear a great deal about the need for the engineer to study the social sciences; while you in the teaching profession may have a clear idea of the meaning of that phrase, I shall have to admit that it has been used so loosely and so frequently that the layman is quite badly confused, and has generally developed a dislike for the words, particularly since some of our political friends are even trying to write it in legislation along with "pure science." However, in the articles referred to, we now find discussions of economic matters, finance, human relations, management, government—subjects which a few years ago would have been taboo in any technical magazine.

I should like to mention also another

* Presented at Meeting of Illinois-Indiana Section, University of Illinois, May 11, 1946.

evidence of the changing ideas regarding the engineer's field of activity. The Engineers' Joint Council, which is made up of presidents, past-presidents and secretaries of the four founder engineering societies, and the chemical engineers, has standing committees working on subjects which are of interest to the profession and of national interest as well. One of these committees is studying the economic status of the engineer, under which title you will find discussions on labor relations, wages, etc. Another committee is preparing a report on the organization of the engineering profession and is canvassing the entire field with the intention of making a thorough diagnosis of the situation, and after the essential information is collected, it will make recommendations. Another committee offered the help of the profession to the State Department on the industrial disarmament of Germany and Japan. At the request of the State Department a report was prepared on Germany which was very well received by both the State Department and the Army. A similar report on Japan is nearing completion. In the hearings on the MacMahon Bill, regarding the application of nuclear energy, representatives of these organizations presented the necessity for engineering representation in the organization of the advisory committee to the commission, and supported the arguments of Mr. Klein of Stone & Webster, who had made a personal appearance. This was so effective that Senator MacMahon wrote Mr. Klein that he apparently had the support of the entire engineering profession. The engineers, along with representatives of the scientific societies, presented a resolution to the President regarding the drafting of student engineers and the subsequent depletion in the number of new engineers available for industry. During the war and previous to it, the American Society of Mechanical Engineers, with which I am best acquainted, worked with the Ordnance Department of the Army on industrial preparedness, and during the war built up its usefulness in special research which was requested. Some time ago the same society offered its service to the Navy, an offer which was very well received and apparently much appreciated; since that time the Navy has asked to be represented on some of our committees conducting work in which they are particularly interested, and has shown a willingness to cooperate. The Navy is probably the largest mechanical engineering organization in the world, so it is most important that there should be a very close tie-in between it and the society which represents the mechanical engineers. What the other societies are doing, I cannot say as I am not so well acquainted with their programs, but I do know that the civils are taking a very active interest in political matters. The work of the engineering societies in cooperation with industry is too well known and too well established to justify much discussion at this time.

Although we may have been frequently told that engineers have not done a good job in national politics, I would like to remind you that one of the outstanding men of our profession has made a reputation as an authority on relief work in devastated countries. This is the biggest job of human engineering the world has ever seen, and the recent appointment of Mr. Hoover is just recognition of his ability and fitness, even though he is an engineer by training and profession.

Engineers, you will find, are getting

into local politics and are taking a more active part in community affairs—they are working on village boards and committees of various kinds, school boards, and are members of boards of trustees of universities and colleges. I think we can flatter ourselves that the appellation "engineer" has better standing then it has ever had before.

Probably because the engineer's technical work requires that he deal with facts which are, of course, impersonal, and that he must make a qualified, unbiased analysis of cold facts in reaching a proper conclusion, the engineer has too often created the impression that he is lacking in those human attributes which enable people to get along with each other. He is considered an introvert. This is an impression which must be corrected. Quite frequently some apparently insignificant thing calls this to our attention. Even the comic strips have recently commented on the engineer's lack of understanding of human relations, and though we laugh, when we read these "funnies," we must not forget that they are read by millions of people every day, young and old, and that they do represent the thinking of certain people and influence the thinking of probably hundreds of thousands of others. I am referring to a recent line in "Harold Teen" in which Harold asks Lillums to give up her career as he is going to be a great engineer, and her reply is "Oh! Engineers have no romance."

The great majority of graduate engineers go into industry and they look forward to the time when they will assume positions in management. Their preparation for this, however, is altogether too meager, and probably because this matter has not been properly and sufficiently stressed in their educational programs, they fail to realize the importance of good personnel relations. I should like to repeat that in my opinion the most important time in the young engineer's career and the time at which he is most carefully watched is when he is given the responsibility of directing the work of others. Whether or not he is a good manager will determine his future success. Too often in discussing matters of this kind, the statement is made that a certain young man under consideration is well educated technically but that he lacks managerial ability and in certain cases, has a difficult time getting along with people. In these days of large organizations, management and its associated "human relations" are becoming increasingly important.

As the importance and scope of the engineer's work increases, and as he assumed more and more positions of responsibility, it is only natural that he and his profession should come in for more criticism. As for myself, I welcome such criticism for it merely emphasizes the shortcomings which some of us in industry have been preaching for years. I should like to quote from a talk given by Mr. Robert W. Johnson before the American Management Association last month:

"Unfortunately the graduates of our great engineering schools and the products of our American universities were not equally well educated in the science of human engineering. Recently it has become apparent that the greatest technical skill is worth little unless men and women can be persuaded to carry out the decisions essential to making that skill effective. We are now discovering that a scientific and technological understanding of a subject does not develop or produce ability to lead large groups of people into enthusiastic day-in and day-out response. This means that we must have new management—management not only skilled in

the techniques, but equally well grounded in the field of human relations."

While we may think that Mr. Johnson has overdrawn the picture, we must not forget that comments such as his are listened to and widely read and believed. They have a wide-spread influence. We will agree with some of his statements, for they have been made many times before and are not new, but I should hate to believe that the picture is quite as black as he paints it. The great majority of management jobs in industry are filled by engineers so they must have done a fair job compared with what men with other types of education might do, or they would not have been chosen. The fact remains, however, that the engineers have not done a good enough job. Their performance along technical lines has been wonderful but the human relations angle cannot be ignored.

Engineering educators and educators in general have placed a great deal of importance on scholastic standing. The fact that a young man may have attained a position in the top ten per cent of his class, according to scholastic rating, may not be a good indication that he will be a good engineer. If we in industry were doing the job, we would not place so much importance on scholastic attainment, as you seem to think is necessary. A good scholastic standing may indicate good habits of study and by checking his record we may be able to determine those lines of activity in which a student seems to excell, but there are many other qualifications which should be considered. A few years ago I received from the head of the mechanical engineering department of one of our well known universities a booklet in which a page was devoted to each member of his graduating class. Each page bore the picture of a young man, gave his family background, age, religion, etc. It told whether he had supported himself wholly or in part during his educational career, what industrial experience he had had, and showed the grades he had maintained. It also gave a brief description of the individual and a short discussion of his hobbies and extra-curricular activities. I thought I might shock my good professor friend when I wrote and told him that I had studied his book carefully and that I had paid particular attention to these men's hobbies, industrial experience, and to their extra-curricular activities; also, to their family background, because I thought these items would give me a better picture of the individual than I would be able to get from his scholastic rating. I was willing to take his educational qualifications for granted and would be willing to take an average rating in this regard if a young man possessed some of the other qualities for which I was looking. I also pointed out that in entering a large industrial organization a young man's hobbies are frequently a means for making acquaintances and establishing friendships.

Industry is always looking for the exceptional man, and the genius has played a most important part in our industrial and economic development. The genius, however, is a rare bird and is a problem to our engineering institutions of learning because as they follow the usual mass production procedures and subject their raw materials to "go" and "no-go" gages, these men are apt to be screened out. Even if they are fortunate enough to get in, they are frequently dropped in the educational process as they are subjected to gaging from time to time. If

they conform to the requirements and pass the final gage test, they are too apt to look like all the other pieces in the assembly line. There are, however, certain qualities which we think all engineers should possess; one of these is the ability to express himself either orally or in writing, and the ability to prepare reports which are intelligible and conclusive with a minimum of misspelled words and with fairly good English. If a man is unable to express his thoughts properly and convincingly, he is handicapped from the start. On the other hand, ability along these lines will go far in calling attention to a young engineer, provided, of course, that his thinking is sound. Other items are personal appearance and personal conduct. The latter is so closely allied to reliability and dependability that it is given more attention than even you may suppose; certainly more than the young engineer imagines.

The young engineer soon learns that larger and larger organizations are the order of the day—even our engineering schools are becoming examples of mass production. Is it not important then that the engineering profession should be properly organized? To some it may seem that I am getting too far away from engineering, and into the field of politics, but we have heard for so many years that the engineering profession does not receive proper recognition that I am sure it is time that the engineer gave some thought to this particular problem. First of all, we are engineers, and although a man may consider himself a mechanical engineer, an electrical engineer, or some other kind of an engineer, the appellations have no more significance than a given name—they merely serve to identify the particular family or group into which a man's work has landed him. Unfortunately we have been taught along specialized lines and have consequently felt that the mechanical engineer was a different kind of an animal from an electrical engineer, a mining or civil engineer, while in reality we are all members of the same profession. First of all, we are engineers and until all the members of the profession accept that principle, and until those particularly interested in special branches of engineering are willing to make the necessary compromises and concessions to effect a representative engineering concept, and are willing to work together for the common good of the profession, just so long will we continue to hear that the engineer is not being given the recognition which his professional ability justifies and warrants. There has been a recent revival of the trend toward a unified profession—many plans have been discussed, but to my mind, one of the most encouraging is the movement now on foot to combine the student branches of the founder engineering societies to make it easier for a young engineer to follow a broad line of activity during his educational life. This will give him a broader background and a better idea of professional solidity, and in time will draw our present engineering societies closer together. I am particularly glad that the faculty members of our engineering schools are interesting themselves in this development.

With these disjointed comments, what are we going to recommend for the future of engineering education? It is important that the young engineer should know the place of his chosen profession in our social structure and in our economic life. He should be impressed not only with its place and importance in industry, but of its place and importance in the development of

our country and in the assurance of its security. He should understand the responsibility of his profession in our social structure, a responsibility which will be his personally later. He should be taught the ethics of his profession which are the finest and the equal of those of any of the other professions; legal, medical, political, and might even include theological. I sometimes think that engineering ethics are better, or possibly more carefully observed than those of some of the other professions. He should be taught the responsibility of citizenship for after all good citizenship is the foundation of a government such as ours. The engineer has a particular responsibility as a citizen. It seems to me that these are fundamentals which should be impressed on the young student as frequently as possible and as early as possible—they cannot be overemphasized.

He should be informed of the kind of work engineers are doing all over the world and should be impressed with the importance of developing ability in fields not purely technical. The engineer who succeeds and who gets to the top in the engineering profession does not acquire this distinction because of his technical ability alone—he must have those other qualifications which we have been discussing if he is to rise above the common level.

We are all agreed that an engineer must have, first of all, a fundamental technical education. I think that industry would agree that so far as the technical education is concerned, our young engineers are quite well qualified. I think the students in our engineering colleges themselves feel that a good technical education is necessary for them to get started in engineering work; in other words, to get a job. We shall also have to agree that the technical field itself is broadening at an astonishing rate due to the increase in scientific knowledge, and that our engineering educators are put to it to keep up with the parade. Teaching the languages, particularly the dead languages, is one thing—once you have covered the subject you are set because the subject matter does not change; in the technical field, however, you are dealing with a live subject which is continually changing and growing. You have continual demands for special courses but I am sure we have all developed a better appreciation of the shortcomings of highly specialized courses during the past few years because of the educational work carried on by the armed forces. While these served a purpose and filled a need, they did not in any sense give the young men who took them an education—their purpose was to take care of an emergency, which we all hope will not occur again. Cannot we agree then that so far as the undergraduate courses are concerned, the young engineer's education should be fundamental and not specialized. Other things are more important than highly specialized courses in a particular field of engineering. That can be done later either by industry or in special post-graduate study.

I think an example of what I am talking about with regard to highly specialized courses might be the case of atomic energy which is now being discussed by every one. The application of this energy, now that the scientists seem to have pretty well completed their part of the work, is undoubtedly an engineering problem, and just as with radio, television and other innovations, I presume you will be swamped with requests for establishing special

courses in atomic power. I am sure you will agree that the fundamentals of the application of this new form of energy are already taken care of in our engineering education and that any specialization should properly be carried on in work beyond the undergraduate course of study. It is hopeless to try to do a complete job in this one field in the time allowed and it would be a serious mistake to sacrifice a fundamental education for such a purpose when the time could be used much better in some of the subjects which have previously been discussed.

During the years we have heard complaints that industry has taken your best teachers because it could offer more money. I am not sure just how serious this has been, but I do know that in some schools the flow has been in the reverse direction, and that those schools have profited immeasurably. Since these student engineers are being prepared for industry, is it not reasonable to require their instructors to have had some experience in industry? With this background the instructors could speak with much more authority and assurance and their comments would be received with greater attention. As each one of us looks back on his own educational career he will admit that a great advantage of his school life was his contact with instructors and professors who by their own character and personality impressed him, possibly unconsciously, with certain habits, mannerisms, etc., which made a lasting impression and stayed with him as long as he lived.

Assuming that the technical curriculum takes all the allotted time, and there is no opportunity for studies in the humanities, in management, finance, etc., can we not somehow have lectures in the classroom by department heads, professors, or by representatives of industry, and impress on these young men the fact that there is much more to engineering than purely technical matters? I have been told many times that the engineering curriculum cannot be enlarged to take in any of these other subjects but I am wondering if the pressure should not be continued and possibly increased to bring before the young engineer the importance of some of these major items. Having had very little experience in teaching, and never having had the responsibility of making up a course of study, I hesitate to make specific suggestions, but will merely express the thought which I know is growing in industry. Of course we are not all equally gifted naturally, but somehow or other in the course of an engineer's education he must realize that technical qualifications are not enough if he is to be successful, and if he is to fulfill his proper place, even in the business world. He must possess these other qualifications which are becoming increasingly important.

College Notes

University of Nebraska.—1. The Electrical Engineering staff at the University has been augmented by the appointment of Associate Professor Charles W. Rook, lately of the University of North Dakota, who takes up his duties beginning with the second semester.

2. Last September we added to our staff Mr. Ernest J. Ballard, Instructor in Electrical Engineering, who came to us from Consumer's Public Power District of Nebraska. He is a graduate of Clemson College.

Summer School for Mechanical Engineering Teachers.—A five day Summer School for teachers of Mechanical Engineering will be held at Northwestern University, June 14–18. Lectures will include Thermodynamics, Gas Turbines, Supersonic Phenomena, Atomic Energy, Hydraulic Controls, Process Engineering, Materials Processing, Stress Analysis, Kinematics, Lubrication, Materials in Design, Fluid Mechanics, Mechanical Engineering Laboratory, Teaching Methods and Testing of Large Groups of Students. The purpose of the Summer School is to bring teachers of Mechanical Engineering up-to-date on new developments and to discuss the problem of more effective teaching. Much of the material covered in the lectures has not yet appeared in text books. The lecturers will be announced in the near future.

COMING EVENTS

A.S.E.E.–A.S.M.E. Summer School—Northwestern Univ., June 14–18.
A.S.M.E. Semi-Annual Meeting—Chicago, June 16–20.
A.S.E.E. Annual Meeting—Univ. of Minnesota, June 18–21.

University of Pittsburgh.—The University of Pittsburgh's 20-million-volt cyclotron is now producing radioactive elements vital to medical research and opening new horizons in nuclear physics.

The atom-smasher, buried in a hillside on the University campus, will be geared with medical science's new attacks on cancer and leukemia, with research into the secrets of animal and plant growth, and with industrial research in metals, chemistry, and glass. Equally important, it will probe still deeper into the atom to reveal the unknown forces that harbor such tremendous energies.

The 120-ton giant is a cooperative project of Pittsburgh's civic, educational, and industrial institutions. Grants of $82,500 jointly from Mrs. Alan Magee Scaife and the Sarah Mellon Scaife Foundation made possible the construction and six local firms contributed equipment and materials. The cyclotron was built under the supervision of Dr. Alexander J. Allen, Westinghouse Graduate Professor of Engineering at the University of Pittsburgh.

Unique in Cyclotron Family.—While the Pittsburgh cyclotron does not compare in size with the super-cyclotrons which are being built, its special design makes it unique for a variety of functions. It promises to be the most efficient and productive cyclotron for general research purposes.

Radioactive tracer materials are being supplied to medical, industrial, and other research organizations. This is a rapidly broadening field of investigation. Radioactive phosphorus, for example, is a promising weapon against leukemia. Radioactive iodine is used to study thyroid conditions. Chick embryos can be studied with radioactive copper. Virtually every element that makes up the human body can be produced in a radioactive form and traced in its progress through the body.

Pure research into the inner mysteries of the atomic nucleus will also be carried on. While the atomic bomb was the surest possible proof that the theories of the nuclear physicists were correct, we still know very little about the nature of the forces that lock up this tremendous energy in the nucleus. The cyclotron will be used to attack this problem until we find the answers. This virtually uncharted field holds great potentialities for new knowledge that may far outrival the original discovery of nuclear fission.

Last but not least, the cyclotron development and its related activities is part of the University's educational program where young scientists are being trained.

A Vacuum Between a Magnet.—In cyclotron operation, electrically charged particles of heavy hydrogen—called deuterons—are produced inside the vacuum box where they whirl around the circular chamber, receiving up to a 200,000 electron-volt "push" at each half-way point until they are accelerated to 20,000,000 electron-volts of energy at the periphery.

Now whirling at the incredible speed of over 20,000 miles a second—fast enough to encircle the world in less than one second—the ions crash against the target, disrupting its nuclear structure, and rendering it radioactive. The target is then removed and used for treatments or research. The whole process is rapid. Radioactive samples are produced in a matter of minutes.

Planned Before War.—The cyclotron was planned for Pittsburgh's great medical and research center to meet the demands for radioactive materials. The present building was completed in 1942, but installation of the machine was delayed by the war. The cooperating firms are the Westinghouse Electric Corporation, the Gulf Oil Corporation, the Aluminum Company of America, the Carnegie Illinois Steel Corporation, Mesta Machine Company and General Electric Corporation.

Rocky Mountain Hydraulic Laboratory.—Plans are now being made for the second season of operation of the outdoor summer laboratory near Allenspark, Colorado. The establishment of this project was described in the December 1945 issue of the JOURNAL OF ENGINEERING EDUCATION (vol. 36, p. 298).* Students of Hydraulics and members of the Hydraulics Sections or Divisions of A.S.C.E., A.S.M.E., A.S.E.E., and A.G.U. are welcome to join in the research and educational activities of the Laboratory,

* The announcement was mistakenly published under the heading, "State University of Iowa." Actually the laboratory is a separate organization and has no connection with any university.

which is under the direction of a board of trustees headed by Gerald H. Matthes, Consulting Engineer of New York City.

During the first season a small group of engineering "pioneers" opened up an access road, built a bridge, prospected for and found sand deposits large enough to take care of the laboratory's needs for construction and experimental work, and built a small shop building. All members of the group, which included Mr. Matthes, Professor C. J. Posey of the State University of Iowa, Professor Ralph W. Powell of the Ohio State University, Professor Henri J. Putnam of the Université Laval, Quebec, Lyman Flook of the U. S. Bureau of Reclamation, and Professor John H. Dawson of the University of Colorado, expect to return for at least part of the coming season to carry on the program started last summer. The organization owns a 20-acre site near the Rocky Mountain National Park, including a quarter-mile reach of the crystal-clear North St. Vrain Creek. In addition to research projects to be conducted at the laboratory, inspection trips to nearby engineering projects and technical meetings with visiting engineers are planned. The second annual meeting of the corporation will be held on Saturday, August 16.

Those who wish to participate in the Laboratory's program, or who would like to use its facilities for research on a particular project, should communicate with Professor R. W. Powell, The Ohio State University, Columbus 10, Ohio, or Professor C. J. Posey, State University of Iowa, Iowa City, Iowa.

Necrology

Clement Clarence Williams was born in Bryant, Ill., February 21, 1882, and died February 20, 1947. At the time of his death, he was consultant in engineering and industrial education.

Dr. Williams was a member of the Council of this Society in 1920–23; Vice President 1928–29; and President 1934–35. He was a very active member of the Society, attending all national and local meetings, and giving unsparingly of his wide knowledge of engineering education. His death is a great loss both to the Society and to engineering education.

In 1907, he received the bachelor's degree from the University of Illinois; 1909, the C.E. degree from the University of Colorado. He received honorary degrees from many colleges. Dr. Williams taught at the University of Colorado from 1907–14; University of Kansas 1914–22; University of Illinois 1922–26; Dean, College of Engineering, University of Iowa 1926–35; President of Lehigh University 1935–44; 1944–47, consultant in engineering at Madison, Wis.

Dr. Williams was the author of "Design of Railway Location," "Design of Masonry Structures and Foundations," "Building an Engineering Career," "Foundations"; and many articles published in engineering magazines.

T-Square Page

A. S. LEVENS, Editor

1. MIDWINTER MEETING.

The midwinter meeting of the Drawing Division of the A.S.E.E. was held at the Brooklyn Polytechnic Institute, Brooklyn, New York, on Saturday, February 1 at 10 A.M.

The morning session featured a talk by Dr. Otto Klitgord of the Institute of Applied Arts and Sciences in Brooklyn on the Technical Institute movement, a few words by Professor Ming of the Brooklyn Polytechnic Institute on his work on E.S.M.W.T. courses and a report by Professor Harry M. McCully of Carnegie Institute of Technology on the work of the Standards Committee. Professor Rule appointed the following committee chairmen:

(*a*) Committee on Granting Credits. Prof. Ralph S. Paffenbarger, Chairman, Ohio State University.

(*b*) Committee on Minimum Standards. Prof. Arthur B. Wood, Chairman, University of Tennessee.

(*c*) Committee on Visual Aids. Prof. H. B. Howe, Chairman, Rensselaer Polytechnic Institute.

(*d*) Committee on Advanced Graphics. Prof. Frank A. Heacock, Chairman, Princeton University.

The morning session was followed by a luncheon, at which the entire group were the guests of President Rogers of the Brooklyn Polytechnic Institute.

The afternoon session was featured by a paper by Mr. Steven A. Coons of the Chance Vought Aircraft Corporation on the Application of Graphical Methods to Aircraft Design. This was an unusually interesting paper repeated from the fall meeting of the New England Division of the A.S.E.E. The paper started a lengthy discussion. This was followed by a meeting of the Executive Committee of the Drawing Division.

The attendance was in excess of forty. The chief topic of open discussion dealt with means of increasing our emphasis on graphical methods and graphical research. It was tentatively decided by the Executive Committee to make this topic the major theme at the Minneapolis meeting in June.

2. JOHN OPENS THE DOORS. (Editor)

The Men We Want are Within Our Doors

By JOHN M. RUSS

Professor of Engineering Drawing, State University of Iowa

"The way to make good draftsmen out of your students is to teach them to draw." How many times have we heard such learned remarks? Advice that is! Almost as often as "The way to keep a drawing clean is to not get it dirty." Running an able frequency race in this class, if any, is the lament that our high school graduates are of

an increasingly poor quality. "How can we be expected to produce a high standard product from such low grade material?"

This alibi of the University teacher has always annoyed me. It has always given a negative nudge to my respect for the speaker. I have been guilty, too, at times. In moments of frustration, and when effective teaching was not apparent. Then came the dawn. Registrations on the student's subconscious mind summated to conscious expression, and I realized my fault in seeking so lame an excuse.

I have had the opportunity of teaching in four of our nationally-known institutions of higher education. And I have had the privilege of serving this Division nationally in several capacities. On this back-drop of experience my observations find this one fundamental projection:

> The average American youth of the proper aptitudes can be taught to be an excellent craftsman, irrespective of whether he reaches us via the little white school house among the corn fields, or by way of the excellently staffed and equipped high school of a metropolitan area. And by "craftsman," I mean in the broadest sense —culturally and intellectually.

The best University administration concurs in the basic premise that any institution of higher education is most fairly judged more by the quality of its faculty than by any other evidence. In these times of hectic teaching, overloaded schedules, and too many of those we love, let us write in words of fire and sear it on our thinking hearts, that never before in the history of the world has so rich and meaningful a group of raw material been seeking admittance to the fraternity of Engineering. Let us constantly search this happy hunting ground for potential teaching personnel with which to acceptably replace the priceless and distinguished personalities who have been guiding the destinies of this Division and its students. Who in 1970 will be the French, the Higbee, the Hood of their generation? We can anticipate the answer today by judiciously picking and encouraging a chosen few from those about us. Now as never before we are in a position to cease continuing mental adolescence in the teaching area. Now we can enlist and initiate young ADULT minds into the instructional brotherhood.

The high schools are doing all right. It is up to us to acquire and build staff personnel who are qualified to carry the learning curve on up into the quadratic level with an accelerated upsweep.

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